F.B. KEDROV

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LIFE AND DISCOVERIES

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In 1934 a rumour started among journalists that Pyotr Leonidovich Kapitza was in Moscow, that he would not return to Rutherford in England but would stay in the USSR.

'Kapitza, the eminent physicist? Where has he come from?' many would ask.

'What! Don't you know? He has come from England.'

'From England?' people would ask again in surprise: 'What was he doing there?'

'He worked with Rutherford at Cambridge University. They say he did research on the atomic nucleus.'

I recall that the editors of the popular-science journal where I was working at that time associated the name of Kapitza with some sensation. We planned to meet Kapitza to write an essay about him, or invite him to write an article for the journal.

Few people in Moscow knew why the young physicist Pyotr Kapitza had gone to England soon after the October Revolution and stayed there for years. His papers were occasionally published in British and German physical journals. They dealt with original experiments on sophisticated apparatus, conducted at the Cavendish Laboratory.

It was not even clear how to pronounce Kapitza's surname: which syllable should be stressed (the first or the second)? Now, five decades later, many people, if not most of them, stress the first syllable, viz. Kápitza. But that is wrong. Kapitza himself, when giving his name, stresses the second syllable, viz. Kapítza.

In Leningrad Kapitza was well remembered by old staff members of the Physico-Technical Institute headed by Academician A.F. Ioffe. During his frequent trips abroad in the 1920s and 1930s Ioffe often met his former pupil and was aware of his successes in science. During his stay in England

Kapitza paid frequent visits to his home country. When in Leningrad and Kharkov he gave talks about his research work; in summer he would occasionally take a holiday in the Crimea.

Kapitza's foreign study tour lasted 13 years. At the age of 27 he left Leningrad for London with comparatively little experience in science and teaching. But 40-year old Kapitza returned to the USSR as a distinguished scientist who had already been Rutherford's closest research associate and the director of the Mond Laboratory at Cambridge, England's most remarkable physics laboratory of that time.

Kapitza could easily be taken for a foreigner. The impression was strengthened by his ever-present pipe and the foreign cut of his suit. Of course, if necessary, he could express himself in perfect English.

Kapitza was then a Corresponding Member of the USSR Academy of Sciences and at the same time a Fellow of the Royal Society (which is the British 'Academy of Sciences'). At that time such a combination was stunning: it seemed inconceivable.

Several decades have passed. Ever since Kapitza settled in Moscow I, as a journalist and editor, have often visited his institute and kept in touch with him.

This book is made of personal impressions, documents, and a popular exposition of some of Kapitza's major works. I would like to take the opportunity to thank all those who rendered assistance in writing this book. I am particularly indebted to Pavel Evgenyevich Rubinin for his friendly help.

Certainly, far from all Kapitza's research work and inventions are dealt with in this book. A scientist can be judged not only by his work, as is widely believed, but also by the originality of his personality and character. Doubtless, it is one's work and then this originality that make one a prominent scientist who influences the development of science. This book is then essentially an account of Kapitza's personality.

Kapitza has witnessed several epochs in the development of 20th century physics with which he himself was closely concerned. He has seen the triumphs and failures of many scientific ideas that have turned the course of the development of physics and led either to remarkable successes or to illusory and insignificant results. Complex and surprising developments in science could not throw him off balance. He has always

appreciated and realizes full well now that science cannot develop smoothly. Failures and dizzy successes – that is where its dynamic power lies.

Kapitza is a universal scientist. He is an active experimental and theoretical researcher, an outstanding engineer and designer of ingenious and sophisticated machines, a university professor, and an organizer of scientific work. He has a bent for many other fields in which a creative genius can manifest itself: he is fond of painting, literature, and theatre, and keeps abreast of political developments. He meets many people valuing, above all, their knowledge, wit, and original, independent way of thinking.

STEPS

(Petrograd 1894-1921)

Leap boldly onto the shoulders
Of the older generations:
What they have done are only steps—
From there it's more clearly seen!

V. Khlebnikov

Pyotr Leonidovich Kapitza was born on 9 July (26 June, Old Style), 1894 in Kronstadt (Kotlin Island). His father, Leonid Petrovich Kapitza, a colonel in the army engineering corps, worked on the defences of Kronstadt. An educated intellectual man Colonel Kapitza was a gifted engineer who played an important role in the development of the Russian armed forces.

Kapitza's mother, Olga Ieronimovna (née Stebnitskaya) was a very educated woman. She went in for literary, pedagogical and social activities, and these have left their mark in the history of Russian culture. Mrs. Kapitza's printed works can be found in the Saltykov-Shchedrin State Public Library in Leningrad. Of great interest are the publications about her work which covered several decades.

In 1971, an elderly Leningrad playwright told me that in the first post-revolutionary years Olga Kapitza, who had moved from Kronstadt to Petrograd, would play host to men of letters in her apartment. These evening at-homes were for the greater part attended by budding young writers, by students of philology, and by would-be literary critics.

The city was in the grip of hunger, cold and chaos. But the young people who gathered at Olga Kapitza's realized that the October Revolution had destroyed the centuries-old constraints on Russian society and the despotism of autocracy which enforced ignorance and blind servitude in Russia. The revolution dealt a crushing blow to the stifling tsarist censorship and literary bureaucrats and the time set in for the blossoming forth of artistic activities and a renaissance of art. Yet in that atmosphere of profound

Olga Ieronimovna Kapitza with her sons Leonid and Pyotr (right), Kronstadt 1899. Photo by Colonel L. P. Kapitza

upheavals one had to possess great courage and spiritual purposefulness to be concerned about the destinies and prospects of Russian literature and to maintain contacts with one's fellow-writers.

Olga's father, Ieronim Ivanovich Stebnitsky (Kapitza's grandfather), was a prominent mathematician, astronomer, and surveyor. He served on the General Staff in the rank of Major-General and was elected a Corresponding Member of the Imperial Russian Academy of Sciences. Ieronim Stebnitsky was a tireless traveller. He toured many countries on scientific missions (to observe solar eclipses, perform cartographic surveys and carry out other assignments). If love of travelling can be inherited it must be said that this was the case with Ieronim's grandson, Pyotr.

Pyotr Kapitza attended the gymnasium for a year and then moved to the Kronstadt technical school, which he finished with honours 6 years later. Owing to his aptitude and bent for physics and electrical engineering he was allowed free access to the physics room of the school. There he would set up chemical and physical experiments and mend

The Kapitza family, Kronstadt 1904. Pyotr is last on the right. (The girl is a relation.)

instruments. Unintentionally following Newton's example the practical Kapitza would take watches apart and put them together again (though not always with success). He has never lost his interest in watches, and when he was already advanced in years he is known to have mended the watch of an old acquaintance of his.

In 1912 Kapitza entered St. Petersburg Polytechnical Institute. He would have preferred the Department of Physics and Mathematics of Petersburg University but the university admitted only young people with a school-leaving certificate, i.e. those who had finished a classical gymnasium, where Latin and Greek were taught. Those who had finished a technical school had to take additional examinations in these languages, which were not in the school curriculum. It is believed that in the senior forms of school Kapitza was not quite sure which career he should take: he was equally attracted by the professions of experimental physicist and electrical engineer.

At that time the Polytechnic had only one physics department, headed by Professor Skobeltsyn (father of Dmitri Vladimirovich Skobeltsyn, who was later for many years director of the Academy's Lebedev Physics Institute). On 5 November 1913 Professor Skobeltsyn sent a letter to the Minister of Trade and Industry saying that it was necessary to set up another department of physics and increase the staff of both. The letter ended with an excerpt from the resolution of the Institute's Council requesting that the Minister should confirm the appointment of Abram Fedorovich Ioffe, M.Sc. (Physics), as extraordinary professor of the Department of Physics starting from the day of his election by the Council.

On 23 October 1913 Ioffe became a professor of the Polytechnical Institute and began giving lectures in physics. Kapitza was one of his students. Of course, Ioffe continued his own researches in the field of dielectrics of which he was so fond. And he pondered over the problem of how to draw students into scientific work.

Certainly Kapitza did not suspect that a new name had appeared in science, which was to play a part in his life. Ioffe was quick to find in Kapitza a gifted student, and he helped

Pyotr Kapitza (right) and his brother Leonid, respectively, wearing the uniforms of Polytechnical Institute and Petersburg University students

him to become a scientist: later on Kapitza used to stress that he was first Ioffe's student and then Rutherford's.

In August 1914 World War I broke out. The armies of Kaiser Wilhelm II advanced on West-European countries and on Russia. St. Petersburg was renamed Petrograd to eliminate the Prussian flavour from the name of the Russian Imperial capital, and the St. Petersburg Polytechnical Institute became the Petrograd Polytechnic. The successes of the Russian army on the battlefield were very modest. The press, however, was full of jingoistic articles about the invincibility of the Russian soldier and an inevitable victory over the Germans in the not-too-distant future.

Like many other students Pyotr Kapitza, then in his third year at the institute, was called up. For some time he served at the Polish front as a driver with a medical unit transporting the wounded in a truck.

In 1916, Kapitza was demobbed and returned to the institute. Ioffe drew him into experimental work in the physics laboratory that he headed and invited him to his seminar, probably one of the first physics seminars in Russia. At that time contacts between physicists in the form of seminars, colloquia, and so on were just coming into being.

P.L. Kapitza as a war-time driver with a medical unit, Petrograd 1916

A. F. Ioffe's seminar at the Petrograd Polytechnical Institute, 1916. Ioffe is standing by the blackboard, and next to Kapitza (extreme left) are Ya. I. Frenkel and N. N. Semenov (The photo was taken by Kapitza, using an automatic release.)

In 1916 the *Journal of the Russian Physical and Chemical Society* (Physics section) published Kapitza's first scientific paper 'The Preparation of Wollaston Fibres'. It dealt with the ingenious technique of making extremely fine quartz fibres for physical instruments. This work was prompted by a sheer practical need: Ioffe's laboratory could not do without quartz fibres, but they were not available.

According to Kapitza's technique, the fibres were not pulled through dies; instead, they were stretched by means of an arrow shot from a bow. The arrow was dipped in melted quartz and the string was then drawn. The arrow would fly along the corridor and fall on a piece of velvet cloth. The fibre carried along by the arrow solidified in the air. (Incidentally, the bow and arrow were made by Kapitza himself.) The ingenuity Kapitza displayed in preparing Wollaston fibres was evidence of his unorthodox and original thinking. This trait manifested itself with particular vividness when he later worked at the Cavendish Laboratory, and it has remained with him ever since. Kapitza liked to demonstrate this technique to students at his lectures.

In December 1916 F. Levinson-Lessing, a prominent professor of crystallography, appointed Kapitza a member of the commission to draft statutes for the Department of Physics and Mathematics at the Polytechnic. Apart from Levinson-Lessing, the commission included Ioffe, M. A. Shatelen and other well-known Russian scientists. The department was established and began to function after the October revolution. It was headed by Ioffe.

In 1918 under incredibly difficult conditions Ioffe founded in Petrograd one of Russia's first physics research institutes of which he became director. The institute is now called the Ioffe Physico-Technical Institute (Order of Lenin) of the USSR Academy of Sciences. Kapitza was one of the first researchers of the Institute which subsequently proved particularly instrumental in the development of Soviet experimental, theoretical, and applied physics. Ioffe's celebrated school of thought has given the Soviet Union many prominent scientists, including specialists in atomic and nuclear physics.

Fifty years after the Physico-Technical Institute had been organised in Petrograd Ioffe's student Academician Yu. B. Khariton called the historical act of establishing the Institute a 'manifestation of the loftiest patriotism.' It was, of

course, an act of optimistic confidence in the future if one recalls the situation in Petrograd in 1918: according to B. N. Menshutkin, a professor of chemistry of the Polytechnical Institute (and a well-known researcher of Lomonosov's work) economic difficulties had been aggravated to such an extent that in the autumn 'the daily ration was 50 grammes of bread, which was often quite inedible; sometimes the ration was replaced by 100 grammes of natural oats. Dinner served in the canteen generally consisted of inadequately boiled grass soup and a small rusty herring. On top of all that when cold days set in there was an acute shortage of firewood in the city, and in the winter of 1918/19, like the previous one, the institute had no fuel at all; the institute premises were not heated. The situation was more or less tolerable only in the professors' apartment block, in the living quarters of the chemical pavilion and in the few wooden houses that had stove heating. It was due to the lack of fuel that the Institute Council decided to have no classes after November 15. The sittings of the Council continued in the Council hall... until the end of November and were then moved to K. P. Boklevsky's * flat which had a spacious room with three windows, quite suitable (for that time) for the crowded meetings. That winter and the following one the vast pine forest around our institute was cut down for firewood; the name of the area Sosnovka ('sosna' is the Russian for pine, *tr.*) has been preserved only to remind one about the past.' (From B. N. Menshutkin's manuscript 'History of St. Petersburg Polytechnical Institute' kept at the Institute's library.)

A. F. Ioffe's seminar was now held at the new premises of the Physico-Technical Institute.

In 1918 Pyotr Kapitza graduated from the Polytechnical Institute where he stayed on as a lecturer in the Physics and Mechanics Department. Revolutionary events and the break-up of the old social order compelled him for a time to cease his daily work at the institute and to suspend research. The country was isolated from the rest of the world and suffered from devastation and hunger. Part of the

* K. P. Boklevsky was then a professor at Petrograd Polytechnical Institute and Dean of the Shipbuilding Department.

intelligentsia, including many professors and lecturers, had emigrated.

In such a complex situation Ioffe was doing all in his power to keep the seminar going and retain his students – young physicists, including Kapitza, N. N. Semenov, Ya. I. Frenkel, and P. I. Lukirsky. This required courage, a firm belief in the usefulness of one's actions and a kind heart. Ioffe, who possessed all these traits, succeeded.

Many years later, Kapitza addressed an audience in the assembly-hall of the Leningrad Polytechnic. Speaking on behalf of the staff of the Institute of Physical Problems on the occasion of A. F. Ioffe's 60th birthday Kapitza said:

'When we learned that your 60th birthday was to be marked it did not occur to any of us to write an address of welcome. We all made up our minds to come here to greet you in person. Now I'm very much embarrassed that I have no address prepared. The explanation is that when you welcome and congratulate your father or relation it does not occur to you that certain formalities have to be observed. Each of us wants to shake your hand and wish you many happy returns of the day. I wish you many, many years of fruitful work in the field you have created – and you are the creator of Soviet physics. May you be happy! I wish you could be our father for many years to come, the father whom all would love and who would be treated just as well as before.'

Kapitza's words need no comment, for they speak volumes of the way Ioffe was regarded by his students. Despite a great age difference he was on friendly terms with Kapitza until the last days of his life. In 1960 Ioffe died at the age of 80. The late Academician B. P. Konstantinov who talked to his teacher three days before the latter's death wrote: 'I left him convinced that 80 years had not blunted either the sharpness of mind or the freshness of feelings of this wonderful man, and that he was as young and full of creative power as he had been in those remote post-revolutionary years when I first saw him.'

The young participants in Ioffe's seminar would be seated in the laboratory on boxes and stools. A speaker would

make a report followed by a discussion. The rules of the seminar were strictly adhered to. The discussions used to be very vigorous; they evoked an enthusiasm typical of young people of that time. Ioffe's students felt they were participating in serious discussions and making a great contribution to science – a pleasant feeling some people lack! Only the zeal that sometimes made itself felt, and an inordinate assurance of the correctness of their views and judgements, indicated that those taking part in the discussions had only recently graduated from an institute or university. They did not yet realize that a categorical conviction of being in the right was characteristic either of the very young or of hopeless blockheads: an intelligent, educated person would always hesitate before taking an important decision and would not be ashamed to change it if it proved to be wrong.

Apart from discussions of problems in modern physics, research was also conducted as far as was possible. In 1920 Kapitza, jointly with Semenov, proposed a method for determining the magnetic moment of an atom interacting with an inhomogeneous magnetic field.

Almost all the participants in the seminar were experimenters and found themselves in a very difficult position: because of lack of necessary supplies, tools, instruments and even plain wire assembling an experimental installation turned out to be a very complicated and protracted affair. Nevertheless, experiments were performed, and very sophisticated ones at that, like the one whose results Ioffe reported to Paul Ehrenfest in his letter of 18 July 1920.

'Kapitza and I observed the Einstein-de Haas effect in a vacuum without any field when nickel was demagnetized (at 350°). Now we are measuring the molecular velocities in a vacuum by the Fizeau method. But most of the studies are just beginning. Interesting results have been obtained by X-ray photographs of metals (α, γ, δ-iron, crystallization of glass, etc.). This is a new method of analysis, similar to the spectral one. In general, we are full of enthusiasm; what we lack are the literature and the instruments.'

Professor Ya. G. Dorfman recalled: 'For some time I worked with Kapitza in the same laboratory. He did not tell me anything about his work. I did not know exactly what he was engaged in, but his diligence was amazing. In

the laboratory he looked gloomy and taciturn. My fuses blew all the time, and he used to tease me in a very inventive way, though I knew he meant well. I was a second-year student and he was already a lecturer in mechanics.'

The position of theorist Ya. I. Frenkel was enviable: he needed neither materials nor equipment. There was a problem with paper but it was possible to get it. Kapitza once remarked that 'in a theoretician's labours a pencil and paper are his tools and some do not need even this. Thus, Euler, on going blind, did his work in his head.'

For all the other workers in the laboratory experimental physics came first: despite difficulties they managed to conduct very complex experiments displaying great inventiveness and an ability to do everything by themselves without counting on outside help. Just like his experimenter-friends Kapitza developed that ability in himself. Later, due to the rather limited facilities provided by the Cavendish Laboratory, Kapitza would attain very high standards in constructing experimental apparatus. A master himself, he learned to value and admire the work of other masters.

The atmosphere at the seminar was friendly and cordial. Discussions would often last till late at night. The participants could express their ideas and views quite freely. When making a statement no one was afraid of offending his colleagues. The exchange of views was very thorough and unprejudiced, which is typical of a genuine scientific discussion. Many years later Professor Dorfman remarked: 'I've lived a very long life but I have never seen such seminars. Ioffe had the remarkable gift of being quite devoid of any prejudice. He was a very great democrat, and this democracy was the striking feature of his seminar.'

Frenkel, regarded as the most well-read participant, would for the most part expound the latest theoretical discoveries. At that time the sensational works by Rutherford and Bohr dealing with atomic structure evoked exceptional interest among physicists. Of course, Kapitza could not foresee that he would work very close to Rutherford, the great scientist who had, as it were, peeped into the depths of the atom. Frenkel spoke at length about Rutherford and his amazing discoveries. He would also give lectures on various problems of experimental physics and biophysics, which were his major concerns, as well as of related sciences.

The themes of his talks were sometimes very unusual. One time Frenkel tried to define the main distinction between animate and inanimate nature. 'The natural state of any inanimate system is that of stable equilibrium', he maintained, 'whereas the normal state of any animate system, whatever angle it is viewed from (mechanical or chemical), is that of unstable equilibrium and it is the maintenance of this equilibrium which constitutes the essence of life.' Later Academician Igor Tamm, a friend of Frenkel, in explaining the meaning of this statement said that (according to Frenkel) any deviation from stable equilibrium caused by any force produces a counterforce tending to reduce this deviation and to resist it.

Apart from Ernest Rutherford's discoveries at Manchester University great attention was drawn to the works by Marie Sklodowska-Curie at the Radium Institute in Paris. The world was flooded with scientific discoveries in physics, which had completely transformed this science. The fundamentals of modern nuclear physics, quantum theory, solid state physics, the theory of relativity, astrophysics and other sciences were being established. Rutherford had completed his famous experiments in nuclear fission (called disintegration at that time), i.e. he proved that nuclear reactions under specific conditions were feasible. In 1920 he predicted the existence in the nucleus of neutral particles which were later discovered experimentally by his disciple J. Chadwick and called neutrons. Chadwick's discovery in 1932 presaged the mastering of atomic energy.

At that time Petrograd was the scene of numerous revolutionary meetings held in squares, theatres, palaces, at the riding-hall and in the circuses. The streets were filled with red banners. The bourgeoisie hastily fled the capital of Russia. As early as 1917, Frenkel wrote: 'The password "freedom of speech" worked like magic.' Yakov Frenkel related that at the peak of revolutionary and military events, during a meeting in Alexandrinsky Square he climbed on to an improvised rostrum and made a speech, saying that the people should not be confused with the ruling class and the government, that the German and Russian people had been deceived, and so forth.

In November 1920, Ioffe was unanimously elected a member of the Russian Academy of Sciences. Now he had

better opportunities to organize scientific work, and, in the first place, to promote research and the international scientific ties which he thought were very important for the development of science in the young Soviet country.

At the Academy's request a review of Ioffe's scientific works was prepared by Academician Alexei Nikolaevich Krylov (Kapitza's future father-in-law by his second marriage). Krylov's memoirs contain a few lines about the final stage of the balloting procedure – it should be said that voting was in three stages by secret ballot. The meeting was held in the small conference hall of the Academy of Sciences. Ioffe was in the next room at that time, so he could be summoned to provide additional information or answer a question. According to Krylov, a north-westerly wind was blowing that November evening and it was sleety. Trams did not run and the streets were not lit. In the morning the weather had been good and Ioffe had left home with a light coat on, wearing summer shoes. After the meeting Ioffe would have had to walk more than eight miles home to the Polytechnical Institute in a sea of slush. Krylov lived not far from the Academy in Kamennoostrovsky (now Kirovsky) Prospect. He invited Ioffe to stay the night at his place.

'Back home I saw Ioffe was dripping wet and had got chilled to the bone, as the phrase goes. I suggested that he should change his clothes, rub himself dry, and then have a drop of brandy and a good glass of hot punch prepared according to a naval recipe. That was the only wine-glass of brandy and tumbler of punch that Ioffe drank in his entire life. But it saved him from catching cold,' Alexei Krylov recalled.

Many years later Kapitza told me about his scientific trip from England to Paris in 1925. Some days after his arrival in the French capital Frenkel and his wife, and Ioffe and Krylov also came there from Berlin.

One day when Pyotr Kapitza was taking a walk in Montmartre he was approached by some young men, called 'night guides' in Paris, who suggested that he should visit a night club to which they agreed to accompany him for a very small tip. Pointing to Ioffe who was walking a few feet in front Kapitza said: 'Messieurs, papa is over there. Go and ask him. If he doesn't mind I shall certainly be very glad to go with you.' Without suspecting any trick the young men addressed Ioffe: 'Wouldn't Monsieur allow his son to visit

the best night club in Paris? The young man will like it there very much.' Ioffe shook his head in earnest: 'I'm sorry, young men, but I can't let him go. This is against the principles of a loving father and would be a little too much for my modest boy.'

The Paris incident became known to the staff of the Physico-Technical Institute and ever afterwards Ioffe was referred to as 'papa', a nickname which he humbly bore all his life.

Academician Nikolai Nikolaevich Semenov, Nobel Prize Winner, who worked in the same room with Kapitza at the Petrograd Polytechnic wrote: 'I believe no country has ever had a physicist who, like Ioffe, has moulded such a large team of prominent scientists from among his disciples. A free and principled spirit, a devotion of the collective to science, the aspiration to comprehend the inherent reasons for the phenomena occurring in nature – all this is typical of Ioffe's school. Now his former disciples have themselves become organizers of research and are maintaining this spirit in their scientific institutions.'

Ioffe's charm had a special attraction for all those who came into contact with him – his staff, students, scientists from different countries, and artists among whom he had many friends. Although it is impossible to analyze in strict 'scientific' terms the features which give a person such irresistible attraction in the case of Ioffe his wide culture was certainly one of them. People admired the conviction and nobility which manifested themselves in whatever he did. Ioffe always adhered to his own conceptions and ideals. He had a great aversion to time-serving, and anything that was base, dishonest or inhumane was repugnant to him. Ioffe never diverged from the path he had chosen in life, and at the same time prejudice and conservatism, which prevent a scientist from making an outstanding educator, were alien to his nature.

In his reminiscences Academician Ivan Vasilyevich Obreimov portrayed Ioffe as a buoyant personality, always clean-shaven, neatly and tastefully dressed, an interesting and witty interlocutor, and very inventive in giving short replies. Ioffe's culture manifested itself literally in everything. He was fond of (and understood) music and he was well versed in classical and modern literature.

Obreimov recalled the hard times in 1919-1920: 'We used

to walk in autumn slush without overshoes on, and had wet feet; we lived in unheated rooms; food was rationed, or, to put it bluntly, we went hungry. Yet against this background our organizers (Ioffe, in particular) were fully confident that the Revolution was a success, that Soviet power was in control and that culture would flourish in the country.'

After much bustling about Ioffe managed to arrange for Soviet physicists to go on a business trip to Germany and Britain to purchase the necessary physical and electrical engineering apparatus, laboratory equipment, and scientific literature. On Ioffe's recommendation Kapitza was to go abroad together with him on this scientific mission: Academician Krylov who was a shipbuilder and mechanical engineer, and optician D. S. Rozhdestvensky were also to go. People's Commissar of Education Lunacharsky thought there should be a considerable sum in hard currency at the disposal of the scientists. Lunacharsky told Lenin about the forthcoming trip and obtained his full backing. Lenin rang up Deputy People's Commissar of Foreign Trade A. M. Lezhava and ordered that a sizable sum should be set aside for Ioffe's group.

After obtaining a passport for travelling abroad Ioffe left for Estonia on 12 February 1921 whence he was to continue his trip to Germany and Britain. The money transfer was delayed indefinitely, and it was not clear when Ioffe could leave Estonia for Germany. Because of problems in obtaining a German visa he had to stay on at Revel (Tallin). It was a wearisome wait like the one Kapitza would experience later.

At last, on 10 March 1921 Ioffe wrote from Revel:

'I've got a visa to Germany and I'm going to Berlin tomorrow. Probably Krylov will also go there in a couple of days. I have succeeded in securing Litvinov's permission for Kapitza to go to Revel. As for permission for his further passage, either he or I, after reaching Berlin, will take care of that... Kapitza should go to Moscow and by referring to Litvinov's telegram get the passport and go to Revel. In Moscow he must obtain a money order of 50,000 roubles for the X-ray Institute, 100,000 for the Polytechnic, and 200,000 for the Academy of Sciences. Only then will it be easy for me to summon him to Berlin...'

On 11 March 1921, the day he left Revel for Berlin, Ioffe wrote to his wife:

> 'I got a wire from Kapitza yesterday. If he gets the money in Moscow it won't be difficult to obtain an entry visa for him to Germany. I'll arrange it in Berlin.'

About a month passed but no headway was made with the money. In his letter from Berlin dated 7 April 1921 Ioffe wrote:

> 'I haven't made any purchases here, as all the allocations have been cancelled until February 22. If Kapitza has failed to arrange the affair in Moscow the next credits should be urgently approved in Moscow.'

Again Ioffe mentions the above sums in gold equivalent adding £50,000 set aside by the Supreme Council of the National Economy 'for a plant and workshops'.

In Berlin Ioffe began to intercede for a visa for Kapitza, of which he wrote in his letter of 12 April 1921, remarking that the other members of the group had already joined him.

In April Kapitza received a passport for travelling abroad and left for Revel. He went there in low spirits: shortly before he had suffered a great misfortune – his wife and two small children (a son and a daughter) had died.

In May 1921, Kapitza came to England and in early June he already met Ioffe who had come by sea from Hamburg to London. Both of them went to a London suburb where Ioffe was to stay with a friend of his.

Ioffe fully appreciated the art of letter-writing. 'The first impression was depressing,' he wrote. 'Just imagine several thousand small houses standing close to each other and forming a number of streets. On the ground floor of each house there are three bay windows facing the street, with yellow curtains and glazed pots with a flower on the table in the window. On the first floor of each house there is a window with lace curtains. The same picture is to be seen in a thousand houses. Yesterday windows were washed in every house. All the houses are alike – they are dockers' houses. I am fond of the children – apple-cheeked children with open free faces and movements, who are not afraid of grown-ups. The English landscape is much better... Kapitza has been here for some 10 days and has already settled down in London. There is plenty of fruit here: pineapples, pears

and apples. All prices are high. Everything is full of traditions and fixed habits...'

The excerpt from Ioffe's lengthy letter is very emotional. It shows a sharp contrast between revolutionary Petrograd and quiet London, then still the rock-firm capital of the British colonial empire.

Ioffe's subsequent letters to Petrograd testified to his busy activity, partly linked with arranging Kapitza's employment at Rutherford's laboratory.

7 June 1921

'Kapitza has just been here and taken a lot of snapshots which I shall send you. There are many beautiful things here. Today I've called on Sir Richard Gregory, the editor of *Nature.*

18 June 1921

In London I tried to push as much work as possible on to Kapitza to which he does not object, but I also have to fuss about quite a bit.

7 July 1921

I want to leave Kapitza with Rutherford for the winter, if he agrees to take him on; Krasin doesn't mind.

13 July 1921

I've visited Thomson and Rutherford at Cambridge. The latter invited me to tea and agreed to engage Kapitza at his laboratory (Krasin agreed to leave him here to do research). I've seen many renowned people here, but I'd rather tell you about it when I'm back home.'

This is how Kapitza joined Rutherford's laboratory. Exactly 50 years later Pyotr Leonidovich said of Rutherford: 'I owe very much to his kind regard for me.'

In July 1922, a year after he was admitted to the Cavendish Laboratory, Pyotr Leonidovich Kapitza wrote to his mother Olga Ieronimovna:

'I will try to explain to you my situation, in general terms. Imagine a young man who arrives at a world-renowned laboratory situated in England's most aristocratic and conservative university, where royal children are being educated. And so this young man – a complete stranger, with poor English and a Soviet passport – is accepted at this university. Why? To this day I do not know. Once I asked Rutherford about this. He laughed heartily and said: "I was surprised at myself when I agreed to accept you, but anyway I am very glad that I did so..."'

DAYS OF PROMISE

(Cambridge 1921–1934)

Yours are days of promise,
And, heartened with concern,
Dare to show
What Russian soil can raise up
Of her own Platos
And quick-witted Newtons.

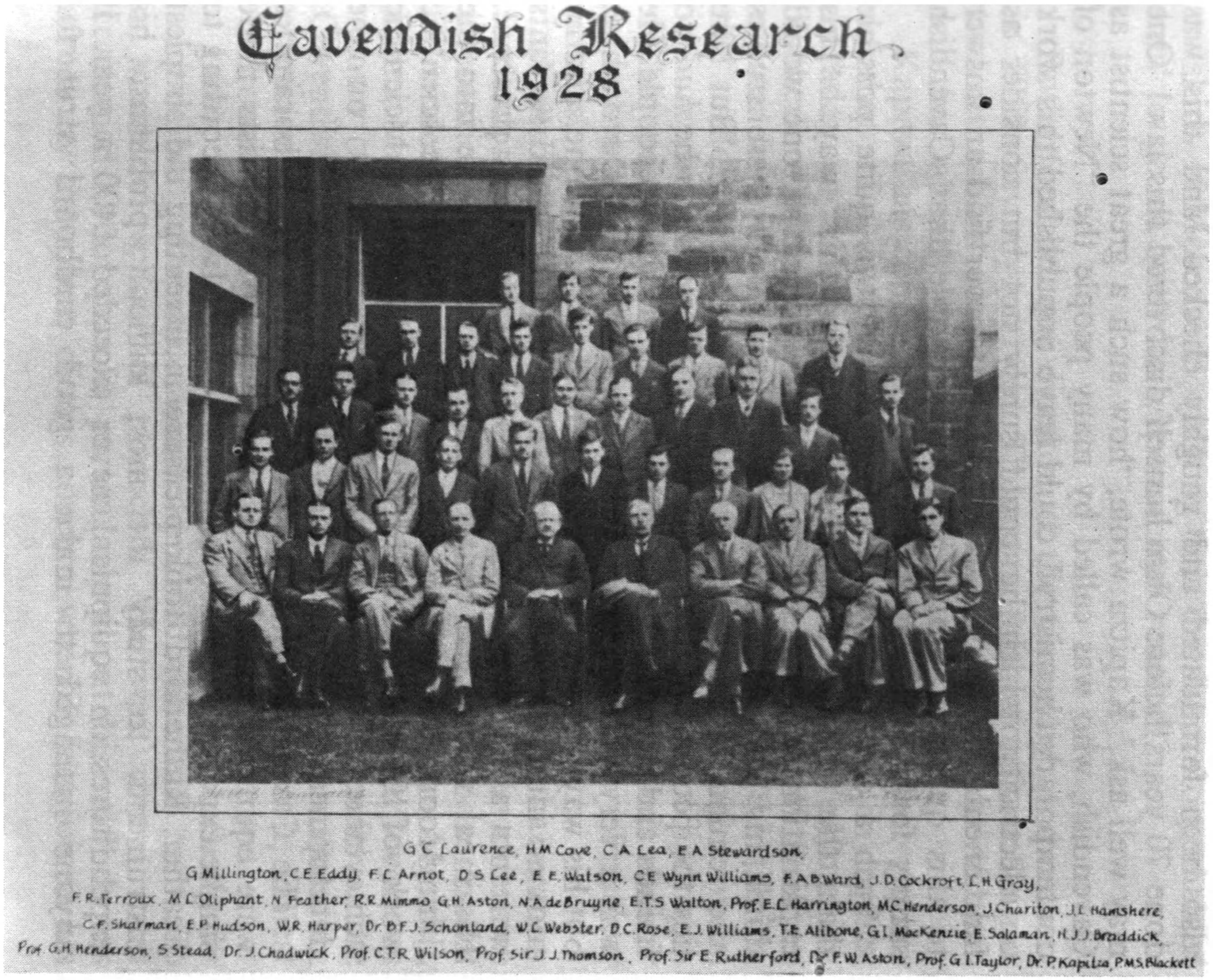
M. Lomonosov

So Kapitza started work at the Cavendish Laboratory. At that time it was considered to be one of the world's major physics centres. The Laboratory had been set up in 1871 with James Clerk Maxwell as its first director and he was succeeded in this post by John William Strutt (Lord Rayleigh). The directorship was then taken over by J. J. Thomson who had discovered the electron. Until 1895, only the undergraduate and postgraduate students of Cambridge University could work at the Laboratory. At Thomson's request this procedure was changed: young physicists who had graduated from universities in the British dominions and other countries began to turn up at the Cavendish Laboratory.

'In the unruffled pre-war years,' wrote Norman Feather, 'scientists from many countries would freely come to Rutherford's laboratory to gain experience in this new and exciting field (nuclear physics). Among them were: Massay and Oliphant from Australia; Kara-Mikhailova from Bulgaria, Goldhaber, Kühn and Rizler from Germany; Bjerge and Jakobsen from Denmark; Ahmed and Bhabha from India; Occhialini from Italy; Sargent and Terry from Canada; Chao from China; Wertenstein, Niewodniczanski and Sosnowski from Poland; Gamov, Kapitza, Leipunsky and Khariton from the USSR; Bainbridge, Oppenheimer and Shenstone from the USA; Bretscher from Switzerland; Schönland from South Africa, and Shimizu from Japan. This list could be easily trebled.'

Kapitza in his first years of work with Rutherford

Having accepted the job as director of the Cavendish Laboratory Rutherford added still more to its fame which had been established by the works of his predecessors. It was none other than Maxwell – considered to be the second greatest physicist after Newton that Britain has produced – who wrote an essay about the forgotten works of Cavendish, in whose honour the laboratory was named. The name of Henry Cavendish (1731-1810) is linked with major research in physics and chemistry. Cavendish did not publish



The research staff of the Cavendish Laboratory, 1928

J. J. Thomson and E. Rutherford are in the centre of the first row; Kapitza is second from the right

his works, and his discoveries became known only after his death when his papers were being sorted out.

Kapitza developed an interest in the personality of Cavendish. He read Maxwell's essay very thoroughly and familiarized himself with other documents about Cavendish. Later, in his essay 'The Scientific Activity of Benjamin Franklin', Kapitza pointed to the fact that among Cavendish's papers Maxwell discovered a manuscript providing experimentally Coulomb's law at least 10 years before the discovery of the law by Coulomb; Ohm's law had also been formulated and roughly checked,–and this was done 70 years before Ohm himself discovered this law! 'One may well ask,' Kapitza wrote, 'how such a great scientist as Cavendish, who was called by many people the "Newton of contemporary chemistry", could leave unpublished this work on electricity, which he could surely not but consider as fundamental. History is hardly likely to ever find an answer to this question, but it is most probable that Cavendish simply forgot to send it to the press.'

Such a conclusion is unexpected but it is quite possible that the events developed precisely this way. 'This explanation seems at first to be unlikely because, one would think, his friends were bound to know about these studies and remind him of them,' Pyotr Kapitza goes on, 'But here lies the peculiarity in the character of Cavendish – he *had* no friends and no colleagues, and in general avoided people. He was a very rich man, a brother of the Duke of Devonshire, but his way of life was an exceptionally unsocial one, and he took an interest only in science. Even his household servants were not allowed to appear in his chambers in his presence. His meal was served on the table before he came into the dining room. Due to this isolation from people, the scientific work of Cavendish, the results of his greatest scientific achievements made in England, had no effect on the development of world science.'

The Cavendish and other British university laboratories were equipped in a rather primitive way. Scientists made simple experimental instruments by themselves. According to Feather, Rutherford 'took pleasure in inventing the simplest instruments to study the most difficult problems: his expenditures on equipment never exceeded £400 a year. If anyone managed to make a good cardboard strut for

photoplates this was considered almost as important as intricate mathematical reasoning. In the history of English science there has never been a greater advocate of extreme moderation in money spending.'

And yet there could be no comparison between the University laboratory and the primitive domestic ones that Cavendish, Maxwell or Strutt had once had and which were destined to disappear for ever. In the 1950s Kapitza took advantage of this obsolete tradition going back to the Middle Ages and established a laboratory at his dacha on the outskirts of Moscow. For a long time this laboratory enabled him to go on with his experimental research.

•

Rutherford became director of the Cavendish Laboratory in 1919. Seventy-year-old Thomson, Rutherford's colleague, had retired but continued to work. Rutherford was 48 then and had already won the Nobel Prize.

Kapitza has compared Rutherford's role in nuclear physics to that of Newton in mechanics, Huyghens in optics, Faraday in electricity and Maxwell in electrodynamics. Rutherford's long years of research resulted in 1919 in an outstanding new scientific achievement: he was the first in the world to observe the transmutation of nitrogen nuclei into oxygen nuclei accompanied by the emission of hydrogen nuclei – protons. He discovered the process of nuclear reactions, which subsequently determined the path of nuclear physics.

When Kapitza was admitted to the Cavendish Laboratory Rutherford was already the recognized leader of an extensive international school of scientific thought. The above list of his students could also include the names of Bohr, Moseley, Hahn, Marsden, Robertson and others. Rutherford's work as a tutor of young scientists was particularly successful at the Cavendish Laboratory where in the 1920s outstanding physicists, such as James Chadwick, John Cockcroft, Ernest Walton, C.T.R. Wilson and Patrick Blackett worked.

Later, Kapitza mentioned more than once Rutherford's remarkable qualities, which enabled him to set up a wonderful school of physicists. 'He was always most concerned about people, particularly about his staff. I was struck by the extent of this concern when I first joined his

laboratory. Rutherford would not permit anyone to stay in the laboratory beyond six o'clock in the evening, and no one was allowed to work on holidays. I protested, but he would say: "It is quite enough to work up to six o'clock. The rest of the time you should be thinking. Those who work too much and think too little are not much good."'

In showing great concern for his pupils and fostering in them an interest in scientific investigations Rutherford adhered to firm principles in moulding a young scientist. 'Rutherford would do his utmost to develop in his pupils independence and originality of thought', wrote Kapitza, 'and as soon as a pupil showed these qualities Rutherford would pay close attention to his work, encourage the beginner, and give a just appraisal of his achievements. He was very particular to give credit for the exact authorship of any idea. He always did this in his lectures, as well as in his published works. If anybody in the laboratory forgot to mention the author of the idea, Rutherford always corrected him. He was extraordinarily precise in giving credit where credit was due.'

Kapitza was one of the group of research students and on Rutherford's instructions worked on a problem related to the investigation of alpha-particles. Chadwick, who soon became friendly with Kapitza, was already giving a course of lectures on radioactivity at Cambridge, which the young Russian attended.

At the 1971 Moscow Colloquium to commemorate the centenary of Rutherford's birth, the British physicist Samuel Devons said that intellectual authority flowed from Rutherford. (Devons had been a research student in the Cavendish after Kapitza had left and was now professor at Columbia University.) Devons described the students' attitude towards Rutherford with the English proverb 'A cat may look at a king'. 'He had so little to be modest about' in treating his students to whom he 'appeared as a patriarchal figure, somewhat archaic, vaguely Victorian in dress and manner'.

Devons' reminiscences date back to a more recent past than Kapitza's. Perhaps, another few years of age did tell on Rutherford. It is interesting that Devons also noted that in his time Rutherford was just as considerate of his pupils. True, punctually at 6 o'clock each evening, the senior members of the Cavendish would tour the laboratories announcing to all that it was time, gentlemen, to close. If this

announcement was challenged, it was promptly reinforced with the advice that (in the words of the Professor), 'If one hasn't accomplished what one wished to by 6 o'clock, it is unlikely that one will do so thereafter. It would be better to go "home" and think about what one has done today, and what one is going to do tomorrow.'

The meeting with the great scientist made a deep impression on Kapitza. For his part, Rutherford was very quick to appreciate the merits of the Russian pupil. In 1961, when Niels Bohr visited the Institute of Physical Problems, Kapitza said the following at the reception in honour of his old friend: 'Let me tell our young physicists that it is necessary for one to choose one's master in science. Niels Bohr was attracted to Rutherford by the same impulses as I later was. There was something irresistibly attractive about Rutherford, just as about Shalyapin. Those who have at least once heard Shalyapin sing were eager to hear him many times over; anyone who was lucky to speak to Rutherford would look forward to meeting him again.'

What sort of person Rutherford was when Kapitza began to work at Cambridge can be seen from Kapitza's letters to his mother dated 1921-1923.

12 August 1921

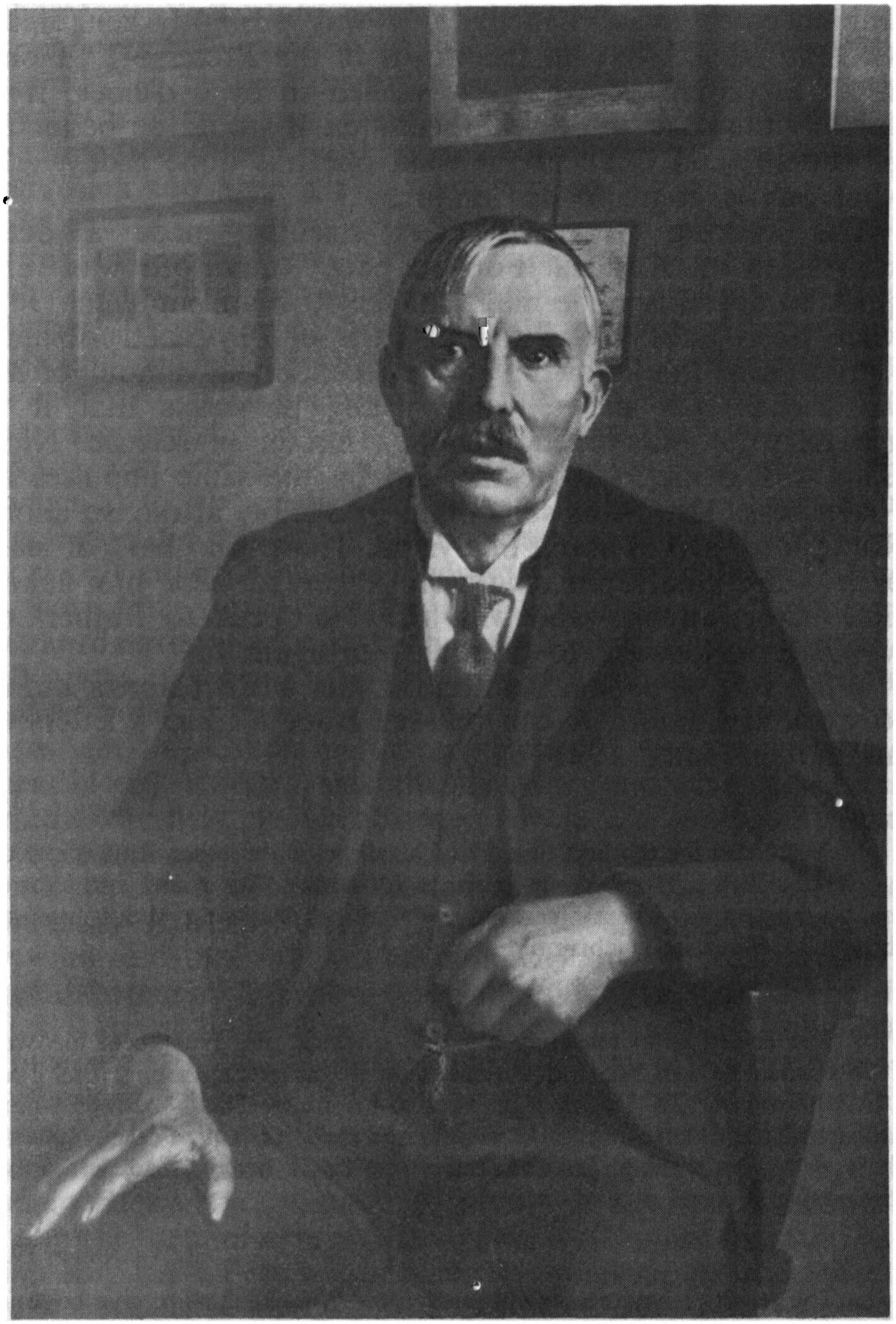
'...Yesterday for the first time I had a talk with Professor Rutherford on a scientific theme. He was very amiable, took me to his room, and showed me his apparatus. There's certainly something charming about him, although at times he is abrupt.

12 October 1921

...Rutherford is increasingly amiable towards me. He greets me with a bow when he sees me and inquires how I am getting along. But I am a little afraid of him. I work right next to his study. This is bad, as I must be careful about smoking; if he should see me with a pipe in my mouth, there would be trouble. But thank God, he has a heavy tread, and I can distinguish it from that of others.

1 November 1921

...The results I have so far obtained are already such as to give hope for a positive outcome of my experiments. Rutherford is pleased, as his assistant told me. I can see that in his attitude toward me. He always says friendly things to me when he meets me. Last Sunday he invited me to tea at his home, and so I observed him there. He is very pleasant and simple. He asked me questions about Abram Fyodorovich [Ioffe]. But... when he is displeased hold onto your seat. He will curse you in the most violent



Ernest Rutherford at Cambridge. Photo by P. L. Kapitza

fashion. But what an amazingly brainy fellow! His mind is absolutely unique: a colossal sensitivity and intuition. I have never been able to imagine anything like it in existence. I am attending a course he is giving, also his reports. He states his subject very clearly. He is a completely exceptional physicist and a very singular personality...

9 November 1921

...As before, I am enjoying my work. I am attending a course of lectures, given by Rutherford himself, on the latest successes in experiments with radium. He is a wonderful lecturer, and I immensely enjoy his manner of tackling and analyzing things... But he is so very ferocious that at times I am a bit frightened, and I am not naturally a timid person...

16 December 1921

...Vacation time is round the corner, and the laboratory will close for two weeks. I asked Crocodile's permission to continue working, but he said he wanted me to have a rest, because a person must rest. He has astonishingly improved in his attitude to me. Now I am working in a room of my own – this is a great privilege here... A comical thing occurred, which is worth describing: a dinner at the Cavendish Physics Society. Membership is for males only, and one becomes a member automatically if one works in the laboratory. They give a dinner once a year... There are usually thirty to thirty-five diners... We sat at a U-shaped table, and one of the young physicists was chairman ...We didn't drink much, but Englishmen get tipsy quickly. And it is immediately noticeable. Their features become lively and animated; they lose their stiffness. After the coffee port was served, and the toasts began. The first was to the King; the second to the Cavendish Laboratory... The toasts were supposed to be as funny as possible. These English greatly love to jest and joke... Between the toasts songs were sung... In general, one can do at table anything one likes: one can squeal, shout, and so on. All this had a rather wild aspect, yet very distinctive. After the toasts, all those present mounted their chairs, and crossing arms, sang a song in which they recalled all their friends... It was very amusing to see such world luminaries as J. J. Thomson and Rutherford standing on chairs and singing at the top of their voices... At midnight everyone went home, but I reached my rooms only at three in the morning, for there were a few who had to be taken home. I assure you that I was among those who were taking the others home – and that is more pleasant. Apparently my Russian stomach is better adapted to alcohol than an English one...'

In this letter Kapitza calls Rutherford 'Crocodile'. The point is that Rutherford had a loud voice, and could not modulate it. The powerful voice of the master on meeting someone in the corridor would warn those in the laboratories that he was coming, and the staff would have enough time 'to collect their thoughts'. This gave Kapitza

a reason to call Rutherford 'Crocodile'. One is tempted to associate Rutherford's heavy tread with the ticking clock that the Crocodile had swallowed in the children's story *Peter Pan*: ever afterwards this sound warned the children of the terrible beast's approach (but Kapitza never touched on this subject).

16 February 1922

'...Today I talked to Rutherford... You won't believe what an expressive mug he has, it's simply a wonder! He asked me to come to his study. We sat down, I looked at his face (which was fierce) and for some unknown reason felt like laughing, so I began to smile. Just imagine, Crocodile's mug also began to smile, and I was about to burst out laughing when I remembered that I must behave respectfully, so I began to state my case... Then seeing that he was in a good mood I told him of one of my ideas. It concerns delta radiation whose theory is quite obscure. I provided my own explanation. A rather complicated mathematical calculation confirms this idea well and explains a number of experiments and phenomena. Up to that point, those whom I had told about it had found my conjectures too daring and were very sceptical about them. At the lightning speed so typical of him Crocodile grasped the essence of my idea and – just imagine – gave it his approval. He is a straightforward person, and if there's something he doesn't like he is so scathing that you feel utterly at a loss. But here he was, praising my idea highly and advising me to get started on the experimentation to prove my theory. He has a devilish intuition. In his latest letter to me Ehrenfest calls him simply 'god'. This favourable opinion was a great encouragement to me... It is very amusing here: if the professor is nice to you this also tells at once on all the others in the laboratory – they also become attentive to you. Yes, mother, Crocodile is really unique... I'm not timid but with him I become quite reticent...'

6 July 1922

...Here they often do research so absurd in its ideas that it would be ridiculed in our country. When I inquired why these investigations had been undertaken I learned that these were simply young researchers' ideas, and Crocodile is so pleased when someone can show his worth that he not only permits that person to work on his own topics, but also cheers him up and tries to put some sense into these occasionally absurd ideas. The absence of criticism, which certainly kills individuality, of which [criticism] Ioffe has an excess, is a feature characteristic of Crocodile's school. Another factor is the desire to obtain results. He is very anxious that a person should not work without achieving results, for he [Rutherford] knows this may kill a person's desire to work. Therefore, he doesn't like to set a difficult task. If the theme set is difficult it means he simply wants to get rid of the man. In his laboratory it just could not happen to me that I would toil for three years over one piece of research, struggling

against difficulties. Crocodile's permission for Lowerman's * arrival is the best proof that he's kind to me...'

The cited excerpts show how the young Russian scientist was sizing up Rutherford and his entourage. Many years later Pyotr Kapitza created a wonderful analytical image of the venerable physicist in his reminiscences about him: the initial version was published by the journal *Uspekhi Khimii* (Advances in Chemistry) in December 1937.

In 'Reminiscences about Professor Ernest Rutherford' Kapitza wrote: 'In his appearance he was rather stocky, and taller than average; his eyes were light-blue, always very joyful, and his face most expressive. He was a lively man with a loud voice which he found hard to modulate; everyone knew this and by his intonation one could judge whether the professor was in high or low spirits. His entire manner of communicating with people showed from the very first word his sincerity and simplicity. His replies were always brief, clear, and exact. He reacted immediately to whatever he heard from you, no matter what it was. Any problem could be discussed with him – he would willingly begin to talk about it there and then.'

This description could be reinforced by Niels Bohr's story of how he had spent many hours in Rutherford's study. Sometimes they were also joined by Kapitza. Bohr wrote that they had discussed 'not merely new prospects of physical science but also topics from many other fields of human interest. In such conversation one was never tempted to overrate the interest of one's own contributions since Rutherford after a long day's work was apt to fall asleep as soon as the discourse seemed pointless to him. One then just had to wait until he woke up and resumed the conversation with his usual vigour as if nothing had happened.'

Apart from attending lectures Kapitza had to complete his practical training in physics which was compulsory for all beginning to work at the Cavendish. The studies were

* E. Ya. Lowerman, an electrician and mechanic whom Kapitza had known when in Petrograd. Later Lowerman worked with Kapitza at Cambridge and for some time in Moscow.

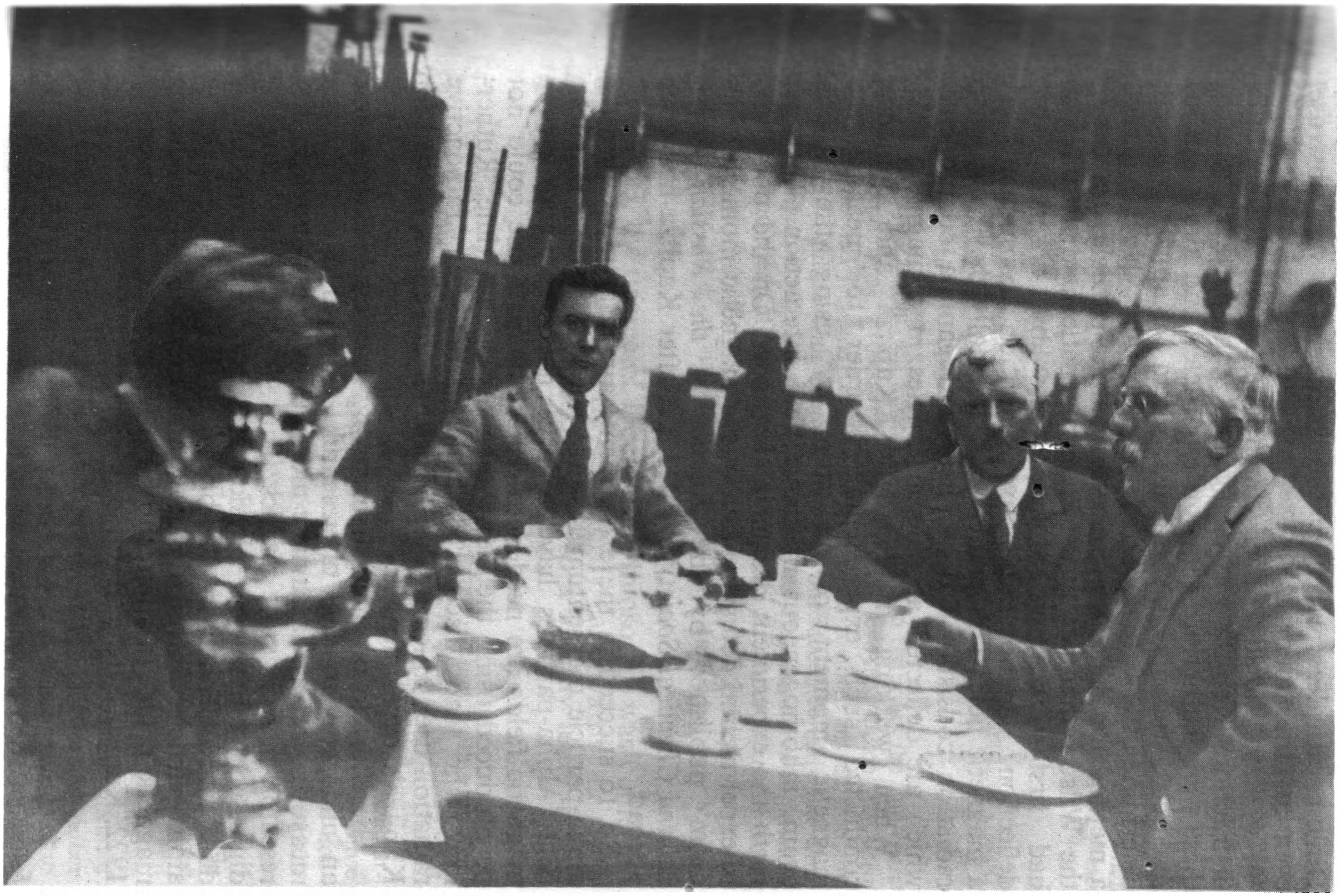
supervised by James Chadwick and scheduled for two years, but Kapitza, to everyone's astonishment, had completed them within two weeks and won the respect of the staff members of the laboratory, including Rutherford himself. This respect was also enhanced by the seminar organized by Kapitza soon after he came to Cambridge, and called the 'Kapitza Club', at which students and young lecturers familiarized themselves with interesting scientific problems, discussed the results of their own research, and now and then held discussions on most diverse questions, including those very far from physics. In his letter to his mother dated 21 October 1923 Kapitza wrote:

> 'The meetings of our circle of which I am the initiator are also a form of relaxation. It's going very well; our discussion is free and easy. Now, Crocodile is also planning a colloquium at the Cavendish.'

'Pyotr Leonidovich brought Russian traditions with him to England,' commented Academician Yu. B. Khariton who worked with Rutherford in 1926. 'He held weekly get-togethers, which united a compact group of those most active in Rutherford's laboratory, and it was at Kapitza's that this seminar was held. As you see, there was not only something for us to learn when staying abroad; at that time Pyotr Leonidovich had already brought something new to Cambridge and the foreigners had to learn quite a few things from us.'

Later Niels Bohr wrote: 'Of the many young physicists from abroad working in the Cavendish Laboratory in those years, one of the most colourful personalities was Kapitza, whose power of imagination and talent as a physical engineer Rutherford greatly admired. The relationship between Rutherford and Kapitza was very characteristic of them both and was, notwithstanding inevitable emotional encounters, marked from first to last by a deep mutual affection.'

Mark Oliphant recalled in 1972 that in his early years in the Cavendish Laboratory he was greatly stimulated by Kapitza whose general approach to science appealed to him: 'His desire to know more about any subject under the sun showed him to be a deep and natural seeker after knowledge, and led him to found the "Kapitza Club" where his probing questions always threw more light upon the question under discussion. He did not hesitate to tackle even authorities like



Tea in Kapitza's Magnetic Laboratory after a meeting of the Laboratory's governing board, late 1920s. Photo by A. A. Kapitza

Dirac about ideas, which, at the time, seemed very abstruse, even to other theorists.'

As has already been mentioned, on Rutherford's instructions Kapitza was engaged in alpha-particle research; these were Rutherford's favourite particles, and almost all his research students investigated them. Kapitza was to determine the alpha-particle momentum. He suggested a method for deflecting a beam of alpha-particles traversing the Wilson chamber in a strong magnetic field. Rutherford had first discovered alpha-particles by observing the deflection of the radioactive radiation components in a magnetic field. This proved experimentally that radioactive radiation consists of alpha, beta and gamma components, which are deflected at different angles in a magnetic field.

When working in Petrograd Kapitza and Semenov conducted such experiments in order to measure the magnetic moment of an atom by using the atomic beam – inhomogeneous magnetic field interaction. They set forth the experiment design in the paper 'On the possibility of experimental determination of the magnetic moment of an atom' published by the *Journal of the Russian Physical and Chemical Society* in 1922, i.e. after Kapitza had gone abroad.

So, to succeed in the experiments aimed at measuring the alpha-particle momentum Kapitza needed a strong magnetic field. Alpha-particles have a large mass, therefore strong magnetic fields are needed to deflect them. These could not be produced using the electromagnets of that time. Rutherford who had discovered alpha-particles in radioactive radiation used much weaker fields than those now needed for Kapitza's experiments.

The effort to produce super-strong magnetic fields became an independent line of research and led Kapitza from measuring the alpha-particle momentum to conducting other research in solid state physics. Thus, for the time being, he digressed from nuclear physics. However, the theme of his doctorate defended in Cambridge in 1923 was 'Passage of alpha-particles through matter and methods of producing magnetic fields'. In a letter to his mother dated 29 November 1922 Kapitza wrote about this work:

'In a way, today is a historic day for me... Here a photograph lies before me: there are only three curved lines on it, showing the flight of an

alpha-particle in a magnetic field of terrific force. These three lines have cost Rutherford £150, and their cost to me and Emil Yanovich [Lowerman] was three and a half months of hard work. But here they are, and everyone at the university knows and talks about them. Strange: only three curved lines! Crocodile is very pleased with these three curved lines. True, this is only the beginning of my investigations, but already from the first photo a number of conclusions can be drawn, conclusions which until now were either not even suspected or could only be guessed from circumstantial evidence. Many people came to my room at the laboratory to see these three curved lines, and to admire them...'

In another letter to his mother from Cambridge dated 4 December 1922 Kapitza wrote:

'These days I feel myself a kind of celebrity. On Saturday the 2nd there was a reception at Professor J.J. Thomson's for the Dutch physicist Zeeman who had just arrived... Of course, I had to force myself into my evening suit. I talked with Zeeman, and was introduced roughly like this: here is a physicist who solves such problems as are considered impossible (to solve). And these mighty ones buttonholed me for about twenty minutes until I slipped away into a corner... Today Zeeman and Lord Rayleigh (the younger) have paid a visit to my laboratory and seen my work...'

In 1923, the degree of Doctor of Philosophy was conferred on Kapitza at Cambridge. Shortly afterwards he was awarded the Maxwell scholarship. In a lengthy letter to his mother of 15 June 1923 he wrote:

'Yesterday I was made a doctor of philosophy... Achieving this rank has cost me so much that I am almost penniless. It is a good thing that Crocodile has lent me some money and I will be able to go for a holiday... Here is what has recently happened to me. This year the Maxwell scholarship is being offered. It is awarded for three years to the best of all those working in the laboratory, and the winning of it is regarded a great honour... On Monday which was the last day to file applications, Crocodile summoned me to his office and asked why I was not putting in for it. I replied that I considered my salary adequate and, besides, being a foreigner and a guest, I should be modest... He said that my foreign origin was in no way a bar to getting such a stipend... For me, bird of passage that I am, this [honour] is of course of no consequence whatever. But Crocodile apparently could not understand my way of thinking, and we parted rather stiffly. Of course, my refusal somewhat puzzled and offended him... Despite this, I am sure that I behaved correctly. Yet I am also rather bothered by a feeling that I offended Crocodile, who is so infinitely good to me... But, obviously, all will end well.

Before his departure (he has left for a month's rest) I met him in the hall. I was just then returning from the degree ceremony. I asked him, bluntly, "Don't you find, Professor Rutherford, that I look wiser?"

"Why should you look wiser?" he was intrigued by my unusual question.

"I've just become a doctor," I replied.

He immediately congratulated me, and said, "Yes, yes. You do look considerably wiser, and you have had a haircut at that," and he laughed.

Taking such liberties with Crocodile is generally very risky, because in most cases he sends you straight to the devil, and it seems I alone of the entire laboratory [staff] take a chance with such stunts. But when they come off, this shows that our relations are all right. In general I must have dumbfounded him with such pranks quite a few times. At first he is at a loss, then he sends you to the devil. Sush an attitude toward him on the part of a junior is all too unusual. Some six times in the past, it seems, I have heard such compliments from him as "you dolt", "jackass", and the like. But by now he is somewhat accustomed to me. Still, most of the personnel at the laboratory are puzzled as to how, generally, such little tricks as mine are possible at all. But I am terribly amused when Crocodile is so stumped that as a first reaction he cannot utter a single word...'

On 23 July 1923 Kapitza wrote to his mother: '...Crocodile offered me that stipend again. I gave in and filed an application... This prize will be very handy...'

Exactly a month later he wrote: '...I have been awarded the Clerk Maxwell Prize, and with it have come many congratulations.'

When Kapitza started implementing his plans for determining the alpha-particle magnetic moment many experimentors were already obtaining strong magnetic fields using an electromagnet that consisted of a coil and an iron core. The upper limit of the field strength was 50,000 oersteds. This level could not be surpassed because of magnetic saturation of the iron. However strong was the current passed through the electromagnet the field strength would not increase any further after the iron had become saturated.

Attempts were made to increase the size of the installation. The French physicist Cotton, who met Kapitza at the Solvay Congress in Brussels had spent several million gold francs on constructing a 100-tonne gigantic electromagnet in Paris. The gain was insignificant, however, for Cotton's electromagnet proved to be only 25% more effective than an ordinary laboratory one.


P. L. Kapitza, Ph. D. (Cambridge)

Kapitza had to follow another path. He took a solenoid, a coreless coil. He gave up the idea of obtaining steady fields in favour of obtaining only transient fields, i. e. short-time pulsed fields of tremendous strength. Indeed, a solenoid has

no constraint caused by the magnetic saturation of iron. But there is another equally strict constraint; a solenoid requires a much stronger current than an electromagnet does, and here the heating effect of current comes into its own. A limit is attained very quickly. If the current increases any further the solenoid melts.

To avoid catastrophic heating of the solenoid the physicist Jean Perrin proposed to cool it with liquid air at $-190\,^{\circ}C$. Calculations showed that to obtain a 100,000-oersted field this way 25 kg of liquid air per second, or 90 tonnes per hour, would be required to cool the solenoid. The problem seemed technically insolvable.

Kapitza's coil could withstand some thousand kilowatts for 0.01 of a second – during which time it warmed up to $100\,^{\circ}C$. If the experiment were to be continued for one whole second, the coil would heat up to $10{,}000\,^{\circ}C$ and melt.

Within one hundredth part of a second we can already observe all the phenomena which take place in a static magnetic field. To record these observations, of course, special apparatus have to be developed, much more sensitive than man's sense organs. Nowadays, everyone has become used to the idea that a hundredth of a second is a very long period of time – almost eternity as compared, say, with the lifetime of certain elementary particles, which is 1/10,000,000,000 part of a second. But at the time that Kapitza was engaged in determining the alpha-particle momentum, all this was quite new.

When the construction of the installation was well under way Kapitza wrote a letter to Rutherford then on vacation in Cairo:

> 'I am writing you this letter to tell you that we already have the short-circuit machine and the coil, and have managed to obtain fields of 270,000 gauss in a cylindrical volume 1 cm in diameter and 4.5 cm high. We could not go further as the coil burst with a great bang which, no doubt, would have amused you very much, if you had heard it. The power in the circuit was about 13,500 kilowatts – approximately three Cambridge power stations taken together. The accident was the most interesting of all the experiments... Now we know what an arc of 13,000 amperes looks like.'

Kapitza carried out his first experiments using a low-capacity storage battery as a current source. It could be charged within several minutes and then short-circuited

through a solenoid. On closing the circuit the current reached 7,000 A, and the magnetic field intensity 100,000 oersteds, the solenoid being about 2 cm in diameter.

However, much larger powers could not be obtained by means of a storage battery. Therefore, in subsequent experiments it was replaced by a powerful generator built by the British company Metropolitan Vickers Ltd after the design of electrical engineer (later Academician) Mikhail Polievktovich Kostenko from Leningrad. Kapitza also contributed to the development of the design.

A characteristic feature of this machine which was essentially different from such ordinary generators was its bulky 2.5-tonne rotor rotating at the speed of over 1,500 r.p.m. On short-circuit enormous forces were developed within the machine, which could easily destroy it. It had therefore to be made of exceptional strength. The stator was made of steel, the bearings, and connections and other details being made especially strong.

The history of this unique generator was described in detail by Academician M.P. Kostenko in his letter to the author of this book, dated 28 January 1976. Here is the full text of the letter:

'At one of our meetings in London in 1924 Pyotr Leonidovich Kapitza told me that he was having some problems in obtaining the superstrong magnetic fields he needed for further physical studies. Since the experiments required strong magnetic fields for very short moments of time, and I was already experimenting with synchronous generators which operated under conditions of sudden short-circuits, it occurred to me to use considerable current surges when synchronous generators were switched on and suddenly short-circuited.

Pyotr Leonidovich liked this idea very much and asked me to make preliminary calculations. By our next meeting in Cambridge I had made the preliminary calculations having selected such parameters of the synchronous generator that would result in current surges and corresponding magnetic fields of the maximum possible values. The peak power of the generator at current surge was 1,000-1,500 MV·A, the operating cycle being 0.02 s.

Pyotr Leonidovich liked the design, and we decided to submit it to the head of the Cavendish Laboratory Prof. Sir Rutherford and ask him to write a letter to a prominent British professor specializing in electric motors to test the design, as, due to very difficult and peculiar operating conditions, pulse generators essentially differ from ordinary generators in design. Professor Miles Walker was our choice. Having received preliminary agreement to a meeting P.L. and I went to Manchester to see him. He

didn't make any substantial changes in our calculations and approved their results. Then the design was submitted to Sir Rutherford.

Pyotr Kapitza and Mikhail Kostenko proceeded with a patent application. The machine for the Cavendish Laboratory was built by the Metropolitan Vickers plant free of charge, which is often the custom in England. The patent was received on 30 June 1926 (No. 254349) after I had left England for the USSR. The machine was also completed after I had left, therefore, unfortunately, I couldn't attend the opening of the laboratory.

Later, at Prof. Dorfman's request, I designed a more powerful pulse generator for the Institute of Physics of Metals in Sverdlovsk. The generator was built at the Elektrosila plant.'

Nowadays, the idea of a pulse generator is applied in some special fields, largely in testing powerful high-voltage switches.

After the generator was installed at the Cavendish Laboratory Kapitza wrote to Kostenko in Leningrad from Göttingen where he was staying at the time*:

'Address in Cambridge
17 Belvere Road
Chesterton
Cambridge

7 July 1925
Göttingen

Dear Misha,

I had a mind to write to you a long time ago, but have been very busy and only found a moment during these holidays when I came to Göttingen to read a paper here. Everything is all right with the machine. It has been built and tested, and gave, under short-circuit conditions (3,500 r.p.m.), an instantaneous power of 168,000 kV·A at moment *max* at complete overexcitation. Had it been short-circuited at the appropriate moment it could have generated 220,000 kV·A. For experiment we can take 1/4 of this power, i.e. 55,000 kV·A which is slightly more than expected. Of course, this is very good, and even better than we thought. The machine has been brought to Cambridge and installed there. It has taken plenty of time and effort. But, as you see, only a year and 4 months after we contemplated the design of this machine when we worked in St. Mary Road it has been built and installed. Really, this is not half bad. I'm sending you a couple of photographs, one of them showing the machine being taken to the Cavendish.

Now the most difficult problem is that of an automatic switching. This part of the work has proved to be very hard and I have worked at it for 3 months at a stretch. It is made at an airplane factory, as its construction

* Several lines of a personal nature have been omitted from the letter.

resembles the cage distributing mechanism of a high-speed airplane engine. We have to use steel brands which can endure a load of 7.0-9.0 tonnes per cm. This part of the work has not yet been planned...

Won't you come and see the machine? If all goes well, it will be in operation by the end of October or mid-November. How are you getting on and what are you up to? My very best wishes and cordial regards to Olga Vasilyevna and to all colleagues. Once again all the best to you. Looking forward to hearing from you,

Yours Kapitza'

On short-circuit the machine gave a power of 220,000 kW for 0.01 s producing the current of 72,000 A at 3,000 volts; this power is colossal, but was attained only in testing the generator, its actual working power being four times as low. A special switch made it possible to 'cut off' the single wave from the current generated by the machine.

The design of the solenoid and its construction involved great difficulties and hazards and were accompanied by failures, which is evident from Kapitza's above letter to Rutherford in Cairo. When high current is passed through a coil the latter has no time to heat up, but colossal forces are developed tending to rupture the coil, which happened several times.

A copper coil – a solenoid with a small number of turns – was bound round with a steel bandage, but this did not help, for the copper still 'flowed' in spite of these precautions. John Cockcroft was engaged in the estimating of forces affecting the solenoid. According to Kapitza, the whole secret of the coil design turned out to depend on choosing its shape and a winding such that the stresses on the copper reduce to a hydrostatic pressure. The copper was subjected to hydrostatic compression, as it were, and the tensile forces were eliminated. At about the same time Kapitza began making coils from copper-cadmium alloy which was stronger than chemically pure copper.

Kapitza's installation – a powerful generator and a solenoid – still stands out in all its magnificence in the spacious magnetic hall of the Institute of Physical Problems. The generator which was once regarded as a technical achievement now appears an antiquated relic, a fossil monster. The unsightly solenoid is placed some 20 metres from the machine. It stands at such a distance from the source of current for very serious reasons. On short-circuit

there occurs a small 'earthquake' which gives a strong shock to the generator's base. During an experiment this can affect the measuring instruments but when the generator is located far from them there is no such danger, for the experiment lasts only a hundredth of a second.

The success of tests with strong magnetic fields led Kapitza to believe that it was extremely promising to experiment with a field of very short duration. Short time puts a limit on what can be done, but, on the other hand, shortness is most advantageous in an experiment. Not only is it possible to observe phenomena within a hundredth of a second, owing to the high intensity of the pulsed magnetic field (if, of course, photography and special recording apparatus are used); at the same time all disturbing influences which are time dependent, as, for instance, thermal disturbances, cease to be appreciable in many cases.

By using his installation Kapitza obtained magnetic fields of 300,000 oersteds and later, when he continued his experiments in Moscow, of 500 000 oersteds, which is an order higher than it had ever been possible to obtain by means of an electromagnet.

Before Kapitza there had not been such sophisticated experimental installations at the Cavendish Laboratory. Thomson, Rutherford and their disciples as a rule conducted their wonderful experiments by using primitive means – 'sealing-wax and string'. This delighted Kapitza. Speaking of Rutherford's experiments Pyotr Leonidovich would always stress the simplicity of tools by means of which his teacher had attained outstanding results: for instance, when he had proved that alpha-particles are helium nuclei and implemented 'artificial disintegration of elements', i.e. discovered nuclear reactions, and so forth.

However, Kapitza carried out a technical revolution in methods of experimental research before Rutherford's eyes. Kapitza's powerful apparatus and the very principle of conducting experiments made a deep impression not only on Rutherford and his staff but also on other scientists visiting Cambridge. Recalling his visits to the Cavendish Laboratory whose equipment at that time was inferior to that of many US research laboratories the famous American mathematician Norbert Wiener wrote in his memoirs: 'Yet there was one laboratory at Cambridge which involved great

expenditures. This was the magnetic laboratory of the Russian physicist P.L. Kapitza, who designed powerful generators to be short-circuited, and thus put enormous currents through great leads which threshed around like angry snakes under the tremendous magnetic fields thus created... He became the pioneer of that large-scale, factorylike type of laboratory... which is now the standard means of exploring the nucleus.'

Thanks to Kapitza's pioneering effort the Cavendish Laboratory was equipped with an ever larger number of sophisticated installations and advanced instruments and apparatus. Getting ahead of the story I could mention the Cockcroft-Walton high-voltage apparatus: this was used to accomplish the nuclear reactions caused by charged particles accelerated in an electric field (a prototype of the accelerator). Rutherford was always proud to demonstrate this installation to people visiting the Laboratory. Once when showing the installation, he said:

'The atom is always inclined to behave not as an energy source but as a "glutton" devouring energy. This occurs, gentlemen, because atom fission consumes much more energy than the amount released in this way.'

Cockcroft who happened to be there at that time, expressed a different view:

'Sir, I'm certain that scientists will find ways of using atomic energy. The energy consumed in fission will be immeasurably less than the enormous amount of nuclear energy released in this process.'

Kapitza, just like Rutherford, did not then believe that intratomic energy would soon be used. Well, lack of faith in atomic energy was not a sin for Kapitza who was not engaged in nuclear physics. Einstein was not inclined to believe in it, either. But Kapitza's scepticism about the feasibility of using atomic energy did not last long.

When Pyotr Leonidovich obtained a reliable method for researching strong magnetic fields he undertook research into the properties of solids. In particular, he began investigating the properties of metals in pulsed magnetic fields. He did not return to alpha-particles any longer, but their investigation marked the beginning of new and significant work which took many years – experiments at extremely low temperatures near absolute zero, the design of sophisticated instruments to

obtain such temperatures, and development of new principles for liquefying gases (such as helium, hydrogen, oxygen and air).

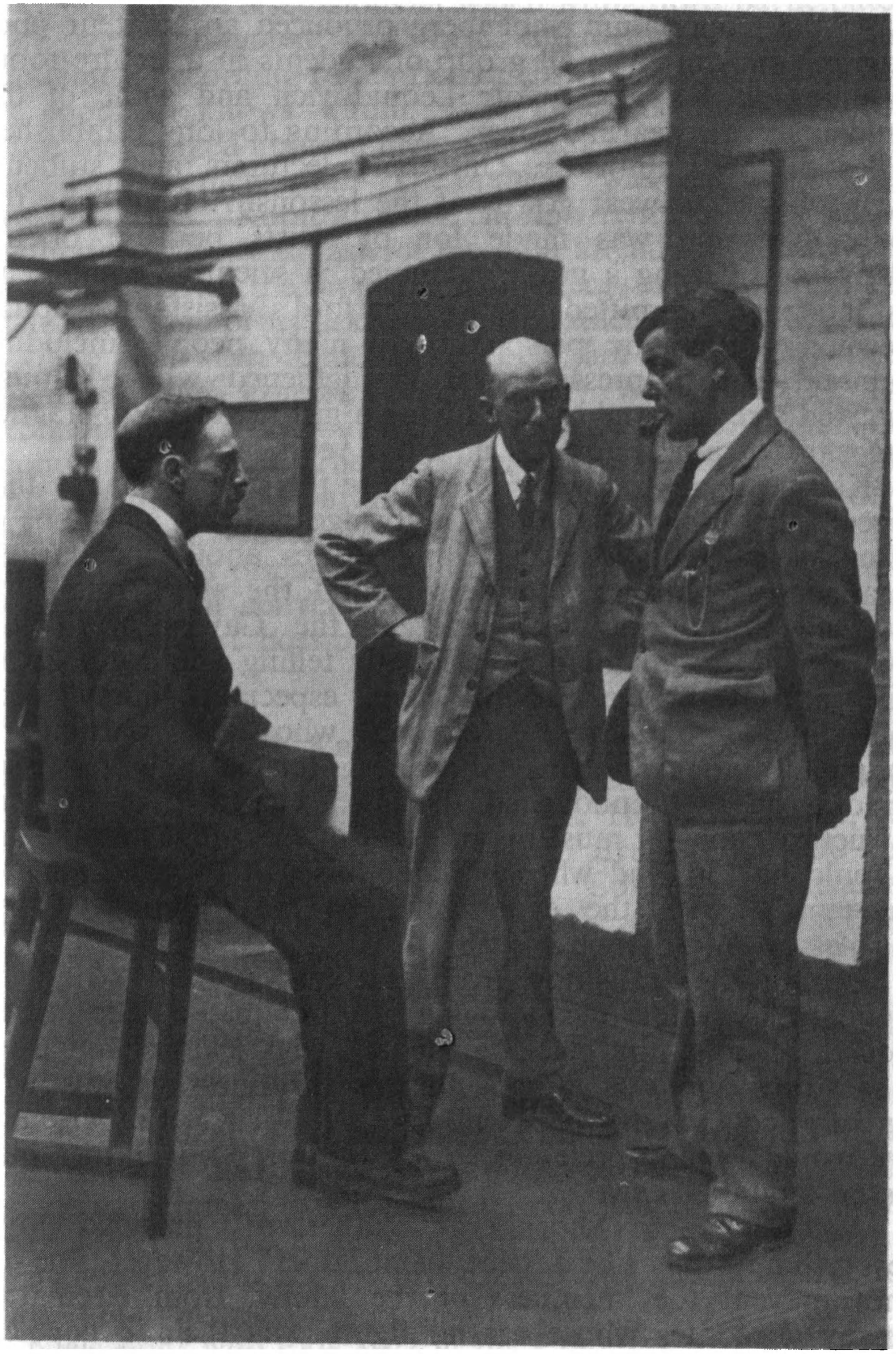
Researches in a strong magnetic field can be exemplified by experiments which resulted in data on the linear dependence of resistivity upon magnetic field for various metals placed in very strong fields. In physics this phenomenon is known as the Kapitza linear law. The linear relationship between the magnetic field and the electric resistance of a number of metals subjected to very strong magnetic fields has for a long time remained one of the most obscure properties of metals. As recently as the late 1950s this was considered to indicate lack of agreement between experiment and theory. And it was only in the 1960s, due to considerable progress made in the development of the theory of metals, that an explanation of the Kapitza linear law was found.

Kapitza also investigated magnetic properties of metals by means of a strong pulsed magnetic field.

In 1924-1933 Kapitza published over 20 works dealing with strong magnetic fields in the well-known physics journals, such as *Proceedings of the Royal Society*, *Nature*, *Physikalische Zeitschrift*, *Zeitschrift für Physik*, *Proceedings of the Cambridge Philosophical Society*, *Uspekhi Fizicheskikh Nauk*, and others.

Rutherford and other British physicists highly valued Kapitza's research into the properties of metals and different phenomena in strong magnetic fields. In 1924 Kapitza was made Assistant Director of Magnetic Research at the Cavendish Laboratory. By that time he was already reading lectures to students.

Addressing the 1971 Moscow Colloquium to commemorate the centenary of Rutherford's birth David Shoenberg recalled that at Cambridge he had attended Kapitza's lectures. Then Kapitza did not speak very good English, as he had not lived in Cambridge long. After a lecture Shoenberg appealed to him to resolve an obvious contradiction in his lecture notes. To Shoenberg's surprise Kapitza said that if he made everything so clear that there were no contradictions, there would be nothing left for students to think about.



Dr. P. Kapitza, Prof. C. T. R. Wilson and a university official in the Magnetic Laboratory, late 1920s

At the Colloquium Shoenberg produced an amateur photograph showing a small group of students in a lecture-room listening to Kapitza. Pyotr Leonidovich and some of the students were wearing gowns. According to long established rules of the Cambridge University lecturers and students were obliged to wear gowns at the lessons. At that time the only exception was made for physicists because of the dangers of getting a gown entangled in scientific equipment.

Shoenberg admitted that Rutherford's assistant Kapitza seemed a romantic personality to many people, including himself. This impression was strengthened when Kapitza 'started a revolution' by employing a girl secretary, a practice unheard of at Cambridge in those years.

Kapitza came to Cambridge before the radical change that occurred there a little later. Cambridge students and dons of those years were fond of telling stories about the curious manners of University professors and the strict rules that reigned at colleges then and at the Cavendish. Today Kapitza does not mind occasionally telling anecdotes about life at Cambridge. There were especially many such anecdotes about those professors who were particularly popular among students. Shoenberg related how professor Eddington first announced that the reciprocal of the fine structure constant must be an exact integer: first he said this should be 136, and when he later raised it to 137 in better agreement with the experiment, he was jokingly called Professor Adding-one.

During the transition from 'sealing-wax and string' to modern laboratory technology all still retained a deep respect for F. Lincoln, the chief technician, who jealously guarded the stores and was famous for his thriftiness. It was with great reluctance that he would give out a few feet of wire and he would usually prefer to search the scrap-box rather than issue anything new.

According to Shoenberg Rutherford presided over everything rather like a 'benevolent father'. However, this did not prevent the 'members of the family' from circulating many anecdotes whose central figure was their 'benevolent father', and he, incidentally, was never offended by such jokes and appreciated their wit even if they were about him. Kapitza wrote about Rutherford: 'At a sharp-witted remark from anyone Rutherford would be the first to laugh, heartily, his laughter drowning all the other voices.'

Generally, the discussions in which Rutherford participated were very animated and held after dinner when the gentlemen, according to a strict English tradition, established by goodness knows whom, were expected to drink port. Once they talked about a meteorite that had fallen in Siberia (the Tungus meteorite). 'The subject was debated in all possible ways,' Kapitza wrote in his reminiscences about Rutherford. "On the basis of the data already at hand we at once calculated the approximate energy and size of the meteorite. One of us asked: 'What mathematical probability is there that such a meteorite could fall in the City right where all the London banks are?" We calculated the probability; it turned out to be a very small one. There were economists present. The question was also raised: "What impact would there be on the British nation were the City, the banking nerve centre, to be destroyed but industry left intact?" In this discussion which lasted two hours, everyone participated. In conversations of this kind Rutherford took the liveliest part possible.'

From Cambridge Kapitza would make frequent visits to France, Germany, Belgium, and the Netherlands to attend congresses and conferences in physics. He participated, for instance, in two Solvay Congresses in Brussels in 1930 and 1933. At that time the Solvay Congresses attracted outstanding scientists from all over the world. Niels Bohr thought they provided a unique opportunity to discuss fundamental problems of physics.

The 1930 Solvay Congress chaired by Paul Langevin was devoted to the 'Magnetic properties of matter'. Papers were read at the Congress by Kapitza and Cotton. Both dealt with the development of experimental technology essential for further research into magnetic phenomena. The papers evoked a great interest; suffice it to say that Marie Curie participated in the discussion. She noted the significance of magnetic experiments for investigations of the fine structure of α-radiation spectra.

Niels Bohr who took part in the Congress wrote later that Kapitza's apparatus made it possible to create magnetic fields of unprecedented intensity within a limited volume. Bohr also wrote that Cotton was quite ingenious in creating large permanent magnets which provided magnetic fields

superior to the previous ones in terms of permanence and volume. However, the field intensity produced by Cotton was not as large as that of Kapitza.

The 1933 Solvay Congress devoted to the 'Structure and properties of the atomic nucleus' was attended by Kapitza and a large group of researchers from the Cavendish Laboratory headed by Rutherford, including Chadwick, Blackett, Oliphant, Cockcroft and Walton. According to Niels Bohr, Rutherford was the central figure at the Congress. As usual, he was extremely active in the discussions.

The Congress was the last one in which Rutherford was able to participate. Four years later he passed away. In his paper 'The Solvay Congresses and the Development of Quantum Physics' Bohr wrote of Rutherford: '...his life in science was extremely fruitful, and in the history of physics there can be hardly found a name of equal statute'. The 1933 Congress demonstrated the real triumph of nuclear physics, much of the credit being due to the Cavendish Laboratory and its director Rutherford. Kapitza, just like all the participants of the Congress, was deeply impressed by many contributions, as well as by the paper on the recent discovery of artificial β-radioactivity made by the young French scientists Irène and Frédéric Joliot-Curie.

At the end of July 1926, Kapitza met Yakov Ilyich Frenkel, an old friend of his and fellow-student of Ioffe's seminar, who by that time had already become a prominent theoretical physicist. Frenkel had come on a short visit to England. In London he was not allowed to come ashore under the pretext that he had no return visa. At that time England would not admit emigrants from Russia, and Frenkel was considered to be an emigrant, as he had no return visa. It was a ridiculous state of affairs. After an exchange of arguments with representatives of the British authorities Frenkel, whom Kapitza described as a simple, determined character, got what he wanted – the authorities gave in under his pressure.

Yakov Frenkel spent the night in London and in the morning went up to Oxford where a conference of the British Association for the Advancement of Science was being held. The conference was attended by Kapitza and Semenov who

welcomed Frenkel. Kapitza introduced him to Rutherford who was familiar with Frenkel's work. At that time Oxford was visited by many foreign physicists who knew Kapitza, Semenov and Frenkel well. Among these were Paul Ehrenfest, Jean Perrin and Max Born.

After one of the sessions the three Soviet physicists got into Kapitza's car and went for a drive to admire the English landscape. Kapitza was in the driver's seat. Meadows and copses flashed by on both sides of the road. Ancient structures built in English Gothic style – castles and country houses surrounded by parks – could be seen everywhere. At times the greenery was so thick that the red roofs and sharp spires of the churches could hardly be seen.

After the conference closed the trio set off for Cambridge. Frenkel and Semenov put up in lodgings in the town. After his marriage Pyotr Leonidovich built a house (No. 173) in Huntingdon Road, where his sons Sergei and Andrei were born. Incidentally, this house remained Kapitza's property for several decades. In 1970, *Vestnik Akademii Nauk SSSR* (No. 6) carried a paragraph entitled 'P.L. Kapitza Hands Over His House in Cambridge as a Gift to the USSR Academy of Sciences'. Kapitza's house in Cambridge would henceforth be used to accommodate primarily Soviet scientists who were on a study course in England.

In Paris in 1926, N.N. Semenov introduced Kapitza to Academician Alexei Krylov's daughter Anna who was then staying in the French capital with her mother. Later Anna married Kapitza. In 1925 Kapitza was introduced to Marie Curie and Paul Langevin at the Radium Institute in Paris. Later Pyotr Kapitza met Professor Langevin on several occasions and kept warm memories of this eminent French physicist. During World War II on behalf of the Soviet government Kapitza invited Langevin, persecuted by the Nazis, to move to the Soviet Union.

After Langevin's death Kapitza wrote that his influence on the development of world physics was very great and that he was not only a great scientist: 'Langevin was also a marvellous teacher; he had many disciples, two of whom – de Broglie and Joliot Curie – received world-wide recognition.' Recalling Langevin, Kapitza mentioned his hard lot: 'Langevin's daughter was arrested and sent to the concentration camp at Auschwitz, where she nevertheless survived. Her husband, Solomon, a well-known Communist,

was executed by the Germans. Langevin had to leave France. This was not easy, for he was nearly seventy. He fled across the mountains to Switzerland. For this an automobile accident was faked; he was bandaged up and carried over the mountains.'

During his years abroad Pyotr Kapitza met many outstanding people and these meetings could not but have a lasting impression on him, for they took place in his youth – and when one is young one's perception of things is so vivid and keen. Rutherford's most outstanding disciple was Niels Bohr with whom Kapitza was very friendly. For his part, Bohr regarded Lev Landau to be his most gifted disciple. In 1930, Landau, then a post-graduate student of the Physico-Technical Institute in Leningrad, spent four months at Cambridge while on a long scientific study tour in Europe. It was then that he met Kapitza who had already become an old resident there (just imagine – he had worked at the Cavendish Laboratory for nine years by then!) Later Lev Landau was Kapitza's closest research associate, heading the theoretical department of the Institute of Physical Problems in Moscow.

Kapitza was best man at the wedding of his friend Chadwick. A photograph has survived which shows Kapitza and Chadwick on the latter's wedding day: both are wearing morning coats and Kapitza, as best man, has a white flower in his buttonhole. His friendship with Chadwick has never been interrupted. On Kapitza's writing desk I have seen an enormous volume of Rutherford's works with a note by Chadwick who had sent the volume to Kapitza.

Kapitza maintained close links with many of his friends. With Paul Dirac he carried out the theoretical work on 'The reflection of electrons from standing light waves' published in the *Proceedings of the Cambridge Philosophical Society* in 1933.

In 1931 the young Soviet theoretical physicist Igor E. Tamm, then a professor at Moscow University, came to Cambridge for a few months. In a letter to L. I. Mandelshtam of 22 June 1931 Tamm wrote:

> 'Apart from Dirac, who has become a close friend of mine, Blackett (whom I like very much) and Kapitza are the people I meet most of all. Kapitza always inquires about you with keen interest and warmth, and has a profound respect and affection for you.

Kapitza (left) and J. Chadwick on Chadwick's wedding day, 1925

I was officially introduced to Rutherford before the meeting of the Royal Society which I came to London to attend. J. J. Thomson doesn't go anywhere and it's hard to see him. Fowler is in America...'

Rutherford always sought to create an atmosphere of mutual friendliness and regard for his staff and disciples, and

he was a great success in this. At the Cavendish Laboratory, for instance, he introduced the custom of five o'clock tea-drinking, the traditional English 'five o'clock tea'. All the researchers of the laboratory would gather for that ceremony. Over a cup of tea they would discuss the results of their research work and share information from different fields of physics, obtained from the scientific literature or from their fellow workers.

Later Kapitza introduced such tea-drinking parties at the Institute of Physical Problems. Generally, they are arranged after seminars. Questions of utmost interest to those present are discussed in an easy and cordial atmosphere. Sometimes a discussion goes beyond the framework of science, touching on the fields of literature and art.

In studying the linear dependence of resistivity on a magnetic field for various metals placed in very strong magnetic fields Kapitza was faced with the necessity of taking measurements at low temperatures. 'Working with the magnetic field and conducting a number of experiments we found that many phenomena, particularly galvanomagnetic ones, were of utmost interest at low temperatures,' he wrote. 'Then we began producing liquid hydrogen and liquid helium and building appropriate apparatus.'

Once the great Faraday placed several small crystals of chlorine hydrate in one elbow of an overturned U-shaped sealed glass pipe, and heated the other elbow over the flame of a burner. The chlorine hydrate would decompose and the pipe would fill with greenish-yellow chlorine. In the same way Faraday would continue to heat the pipe observing several drops of yellow oily liquid settle on the wall of the elbow that was not heated. It was liquefied chlorine. Gaseous chlorine derived from the chlorine hydrate compound in the sealed pipe was subjected to high pressure because of a limited volume. Compressed chlorine turned into liquid. In this way Faraday managed to liquefy eight gases, including ammonia, carbon dioxide and sulphur dioxide. This took place in 1823.

Later, in 1845, Faraday conducted another series of such experiments. He designed an apparatus which could produce pressure of up to 50 atm, and temperatures down to

$-110^{\circ}C$. The scientist hoped to liquefy many gases by means of pressure and deep cooling. His hopes were largely realized, but five gases would not yield to any effort: hydrogen, oxygen, nitrogen, carbon monoxide and methane.

Many researchers continued Faraday's experiments. Among them were two professors at the Jagellonian University in Krakow, Sigizmund Wrublewski and Karl Olszowski, who were the first to liquefy oxygen and nitrogen. In the 1880s one of the world's first cryogenic laboratories was already in existence in Krakow.

On 9 May 1964 the centennial of Jagellonian University was celebrated. Presenting Kapitza with the diploma of an honorary Doctor of Science Professor Genrich Niewodniczanski, who had once worked at the Cavendish Laboratory (but met Kapitza later in Moscow), said that the Jagellonian University was carrying on the traditions established by Wrublewski and Olszowski, and developing cryogenic researches in two laboratories studying low temperatures. Niewodniczanski pointed out that Polish physicists gave much credit to Kapitza and his staff for the efficient organization of these laboratories. The Polish scientist stated that he took pride in the fact that his first experiments in low temperature physics were set up at the Cavendish Laboratory under Kapitza's guidance, even if not directly.

After the discovery of the noble gases – helium, argon, xenon and others – they were also included in the list of gases extremely difficult to liquefy. On 10 July 1908 as a result of long experiments Dutch physicist Heike Kamerlingh Onnes, a tireless researcher in the field of low temperatures, succeeded at long last in curbing helium, the most unyielding gas. Cooling gaseous helium with liquid hydrogen under a pressure of 100 atm he obtained liquid helium. For this work Kamerlingh Onnes was awarded the 1913 Nobel Prize in physics. In 1929, it was still difficult to produce liquid helium and hydrogen. Kamerlingh's laboratory in Leyden was the only one where the technique of liquefying these gases had been mastered.

'The first thing I did', Kapitza wrote, 'was to build a hydrogen liquefier.' Of course, to produce the "coldest" liquid, helium, it was necessary to have liquid hydrogen within easy reach. Pyotr Kapitza's first hydrogen liquefier made it unnecessary to use pure hydrogen as the liquefaction source

product. Instead, commercial (impure) hydrogen was used. The liquefier had an output of seven litres per hour, and a start-up time of only 20 minutes (which was very short for those years) because of the accurate calculation of all the components of the heat exchanger. When the hydrogen liquefier was constructed Kapitza found a new method by which liquid helium could be obtained without preliminary cooling of helium gas by liquid hydrogen. The idea of avoiding the use of liquid hydrogen for the liquefaction of helium was prompted by the fact that hydrogen is explosive.

At the Leyden laboratory helium was cooled with hydrogen that was boiling at reduced pressure. When the temperature was reduced below the helium inversion point the positive Joule-Thomson effect occurred, by means of which helium could be liquefied. On the first day liquid air would be obtained, on the second, 20–30 litres of liquid hydrogen; and only on the third day a small quantity of liquid helium. Kapitza thought that in cooling helium the only way to circumvent the difficulties involved in this complex operation was to use the adiabatic reversible process (i.e. to force helium to expand adiabatically at low temperature performing expansion work). So, Kapitza decided to design a machine capable of withdrawing heat from the expanding helium. The main problem was whether the piston of the machine would work at such low temperatures. As is known the piston of any machine requires lubrication, but at the temperature of liquid helium all substances solidify.

At first Kapitza's idea was to use a turbine since it can operate without lubrication. But helium, like any other gas, has an extremely low specific volume at such low temperatures, whereas the turbine is advantageous only when it works with large gas volumes. Engineers know all too well that only large-size steam turbines can be highly efficient. A turbine of practicable dimensions would have an output of not less than several thousand litres of liquid helium per hour, while for laboratory purposes, where only a few litres per hour are required, the turbine would have to be of an impossibly small size (1-2 cm in diameter).

So, the turbine was no good, but Kapitza was convinced that if very large quantities of liquid helium were ever required this idea should not be forgotten. For the time being, however, the idea of a helium turbine was abandoned.

The proposal of the researcher was complemented by a quite unexpected and very original idea of the engineer. Kapitza designed a simple machine of the piston-and-cylinder type, in which the piston did not need lubrication. The piston was made quite loose, with a clearance of some hundredths of a millimetre. When helium at an elevated pressure filled the cylinder, most of it would naturally escape through the piston-cylinder gap, owing to the low viscosity of helium. However, if the piston was allowed to expand rapidly, a condition could be reached in which only a small fraction of the helium would leak away. The speed of the piston movement calculated by Kapitza proved to be technically feasible.

Kapitza built a liquefaction machine with a fast moving piston while at Cambridge. This work marked the beginning of Kapitza's long studies aimed at creating liquefiers for some of the gases that are most difficult to liquefy – hydrogen, helium, and oxygen.

At the temperature of liquid helium all materials become extremely brittle, which makes them quite unsuitable for this purpose. The search for a suitable material was not an easy one, but in the long run he did succeed in finding one, austenitic steel, which remains ductile down to the very lowest temperatures. The following helium liquefaction cycle was applied: first the helium was cooled to 65 K by liquid nitrogen boiling at reduced pressure, then to 10 K by the gas expansion machine (piston type) and finally liquefied using the Joule-Thomson effect.

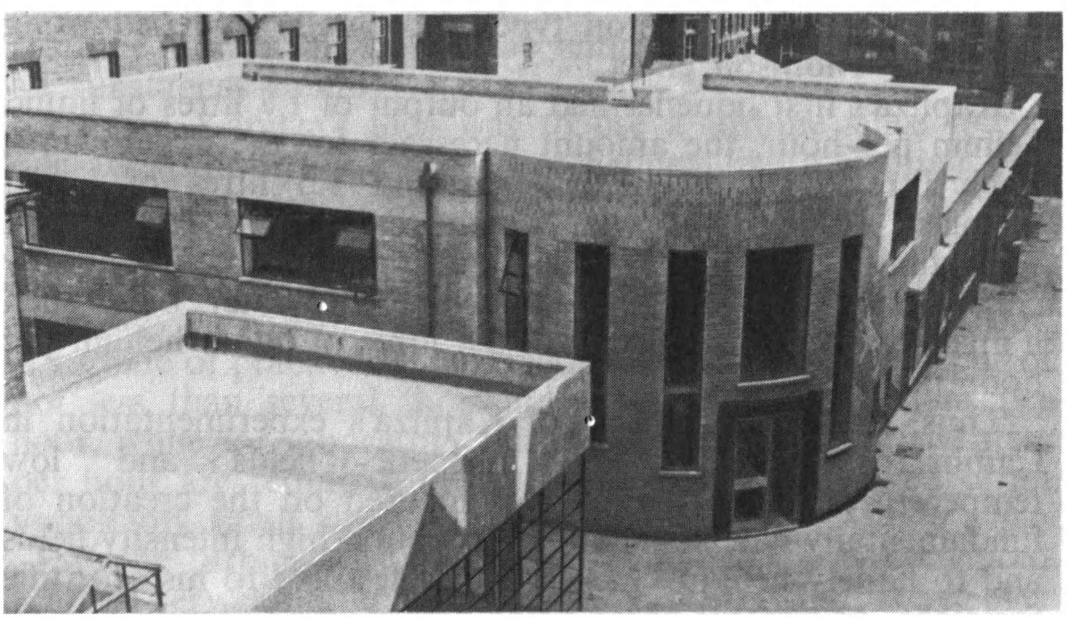
Kapitza's first liquefier had an output of 1.7 litres of liquid helium per hour, the amount necessary for the experiments. Each litre of liquid helium required 1.5 litres of liquid nitrogen. When still at Cambridge Kapitza had an opportunity to make the liquefier more efficient by constructing a double-cycle machine. He later built such a machine with the capacity of 6-8 litres of liquid helium per hour in Moscow.

Thus, the main subjects of Kapitza's experimentation in Cambridge were strong magnetic fields and low temperatures. His attention was focused on the creation of fundamentally new installations to obtain high intensity fields and to liquefy helium. Such a choice testified to his scientific foresight. At present these fields are of great significance in science and technology. In this connection one cannot but

recall the paper Kapitza read at the meeting of the Royal Society shortly before he left for Moscow. Kapitza stated with confidence that superconductivity had good prospects of being applied in different fields of technology. Pyotr Kapitza's prediction is about to be realized in our days.

At one time Kapitza's work seemed not to be related to the researches into nuclear processes which were of particular interest to Rutherford. Later it became obvious, however, that Rutherford, an extremely keen-sighted scientist, clearly saw the importance of Kapitza's experiments for the future of nuclear physics. Several years later, after Kapitza was elected a fellow of the Royal Society (1929), the large Ludwig Mond Laboratory with strong magnetic fields and low temperatures was specially built at Cambridge University and meant to facilitate his work. Rutherford had succeeded in convincing the Royal Society that it was necessary to build the laboratory. It was officially opened in February 1933 in the presence of Rutherford and British Prime Minister Stanley Baldwin.

Kapitza showed to his guests a wonderful picture of a crocodile at the entrance of the Mond Laboratory (Rutherford was well aware that Kapitza affectionately called him



The Mond Laboratory

'Crocodile') carved by the sculptor Eric Gill with whom Kapitza was on friendly terms. Another sight of the Laboratory was the bas-relief portrait of Rutherford, also carved by Gill. Some people did not like it but Kapitza thought it was a fine carving.

Many years later Kapitza decided to make public his correspondence with Niels Bohr and Eric Gill about the bas-relief at the Mond Laboratory. Here are a few letters which could be seen on the notice-board of the Institute of Physical Problems in January 1972.

'Professor Niels Bohr, F.R.S., *10 March 1933*
Copenhagen,
Denmark

Dear Professor Bohr,

I am writing to you at the suggestion of Lord Rutherford to find out your views on the following matter:

As you know, we have just built a new laboratory here with a grant made by the Royal Society. The building has just been opened, and is called the Royal Society Mond Laboratory. You will find the details of the new laboratory in the booklet issued at the opening which I am sending under separate cover. The possibility of my being able to bring to life my experiments with strong magnetic fields has been due entirely to the support of Rutherford, and to acknowledge the great interest he has taken in our work I asked an artist to make a carving of him which has been let into the wall of the entrance hall of the laboratory. As you will see from the picture of the laboratory, it is a modern building, and I thought it appropriate to ask an artist of the modern school to do the carving. I chose Eric Gill since he and Epstein are the two leading sculptors of the modern school in this country.

From the enclosed photograph you will see how he chose to represent Rutherford. It is a fine bit of carving, but a number of people do not approve of it. There are two opinions on the carving–firstly the "conservative" people consider that there is no likeness whatever to Rutherford, and that it is an insult to him, and request its removal; the others, with whom I agree, think that in order to get a complete likeness of a man there exist such methods as photography and taking of masks, but in modern art the idea is to produce a creation of the artist inspired by the model. Eric Gill, when he was told that the carving was not considered to be a good likeness, told how when Lorenzo de Medici complained that the portrait which Michael Angelo had painted was not like him, the painter replied "it will be like you in a hundred years' time". Actually Gill thinks that he has made the portrait too close a copy and would have liked to simplify it still further.

I personally take the following attitude: that this portrait is meant to honour Lord Rutherford, and only at his personal desire would I be

prepared to remove it. Lord Rutherford, on being approached by the "conservative" people, speaking to me, said that he does not understand anything about Art, and is even unable to judge the likeness, although he finds the nose in the portrait too pronounced and more of an Assyrian type. He fails in any case to see any offence in the portrait, and said to me, "You had better write and ask Bohr's view – he knows me well, and also takes a great interest in modern art – I should like to know what he thinks."

Well, I am sorry to trouble you, but would like to ask you for your Solomon's judgement.

Accept our most kind regards to yourself and Mrs. Bohr,

Yours sincerely,
P. Kapitza

Dr. P. Kapitza,
Cambridge,
England

15 March 1933

Dear Kapitza,

It is indeed a very difficult if not impossible task your kind letter has put before me. Even if I have no sufficient qualifications to give a proper judgement in such matters, I have sufficient experience to know, how impossible it is to judge a piece of art from a photograph and without having seen its surroundings. With this reservation, however, the carving of Rutherford looks to me most excellent, being at the same time thoughtful and powerful. I can therefore in no way support the critics of the portrait, and if Rutherford does not object to it and you are satisfied with it, I think that it fulfils its object. I hope that it will remain in its place in many years to come to witness the good work which we all know will be done in your new laboratory. I look forward to see the booklet about the laboratory which I have not yet received, but I am sending these lines off at once, as I am leaving to-night on a skiing trip to get a much needed recreation.

With my best wishes and kindest regards to Mrs. Kapitza and yourself and all common friends in Cambridge from my wife and

Yours sincerely,
Niels Bohr

Professor Niels Bohr,
Copenhagen,
Denmark

20 March 1933

My dear professor Bohr,

I thank you very much for your letter which gave me great joy and satisfaction. It was really very good of you to give us your view so promptly.

I quite realize that it is a difficult task to judge a piece of sculpture from a photograph, but in this case I think the photograph gave a correct impression. We hope that soon we shall have the great pleasure of seeing

you here in Cambridge, and when you look at the carving your views will not be changed.

Accept my most sincere thanks and best wishes,

P. Kapitza

Eric Gill, Esq.,
Piggotts,
North Dean,
High Wycombe

21 March 1933

Dear Gill,

I am sure you would appreciate it if you knew all the fighting I have had lately over your carving. Apparently it irritated some of the most important people in the University so much that they requested that it should be removed. There were big discussions and I had to fight hard and give lectures on "Modern Art and its meanings" and explain such elementary things as the difference between a photographer and an artist. I do not think I have succeeded in changing their minds, but I think I have succeeded in saving the piece of art, which I appreciate very much.

Rutherford, who found himself in an awkward position, as without his authority nothing could be done and he candidly admits that he is no judge of Art, suggested that the judgement should be left to one of his most famous pupils – Professor Niels Bohr of Copenhagen – who is a lover of Modern Art. A photograph of the carving was taken and sent to him, and with the only reservation that he has not seen the actual carving himself, but judging by the photograph, he thinks it to be "a very powerful and thoughtful piece of work".

Everything is now all right, I hope, but I am still surprised to see the extremely formal approach to art existing among most of the people in this country. I had not actually experienced this narrow-mindedness before, but you probably meet with it often. I see they are going to make a fuss about your work on the BBC, and I very much sympathize with you for being attacked through being an individualist in your work.

I should like to have an opportunity of seeing you some time, so if you come to Cambridge don't forget that we can always put you up and it would be a great pleasure to us.

With my most kind regards and best wishes,

Yours sincerely,
P. Kapitza

Dr. Kapitza,
Cambridge,
England

22 March 1933

Dear Kapitza,

We had a visit from Hughes last week and he told us about the fracas over the Rutherford portrait. I am extremely sorry about it – especially,

indeed practically only, because it has been such a nuisance for you. I am very grateful indeed for your championship. Hughes told me that it was all because some people, infected by the Hitler anti-Jew stunt, thought I'd given Rutherford a Jew's nose. Of course that's all nonsense. As I told Hughes, the striking feature of the Jewish nose is not its bridge but its beak. A prominent bridge is rather Roman than Jewish, and these here classical people ought to have been pleased. What a lot of frightful balls it all is.

I am also very sorry to have been the cause of Lord R[utherford] having such a rotten time. Please convey to him my sincere apologies and regrets.

The BBC fuss is over, I hear. The old idiot who thought the sculpture was indecent has been snubbed in the H[ouse] of C[ommons]-so a reporter, who rang me up, said.

I look forward to seeing you again soon. I'm coming down to C[ambridge] to do that inscription on the base of that great fat vase outside the Senate House soon-as soon as we've finished on the L.M.S. hotel at Morecambe. I hope Mrs. Anna is well and the boys.

Thank you very much for your letter!

Yours ever,
Eric G.

Eric Gill, Esq.,
Piggotts,
North Dean,
High Wycombe

24 June 1933

Dear Gill,

The noise about your carving of Rutherford is gradually quietening down. We had a special meeting of the Buildings Syndicate to consider the question. This had to be done as otherwise the conservative people would have felt themselves completely ignored and it is a little too dangerous as the conservative people are always the most important in this world! Still, we had to make them feel that we were not ignoring their opinion-that would offend them more than anything else!

The Buildings Syndicate definitely decided on my suggestion to do nothing with the carving unless you and Hughes consent. So we decided that when you are here in Cambridge to carve the inscription on the Greek vase we will have a small meeting consisting of yourself, Hughes, myself and two or three members of the Buildings Syndicate (the majority is ours!) which I hope will boil down to a general discussion of Modern Art.

Let me know when you are coming, and we shall be very glad if you will stay with us while you are doing this job.

We have had rather a troublesome time with our second boy who has been seriously ill which has upset the household. In August and September maybe I am going to Russia.

I hope your work is going well. Looking forward to seeing you when you come.

With most kind regards and best wishes,

Yours most sincerely,
P. Kapitza

Professor Niels Bohr,
Copenhagen,
Denmark

3 February 1934

Dear Bohr,

All the troubles with the Rutherford carving are now, I hope, over, and it will be left on the wall.

It is impossible to exaggerate the importance of the role you played in saving its life. I should be glad to acknowledge your support by asking you to accept as a present an author's copy of the original. I have spoken to Eric Gill about it today, and he is quite willing to make one in July when he returns from Palestine.

I suppose that the copy should be of the same size and carved in the same stone as the original, provided you do not suggest any alteration to make it suit the surroundings of the place where you propose to keep it.

I hope you and Mrs. Bohr are keeping well.

Yours sincerely,
P. Kapitza

Dr. P. Kapitza,
Cambridge,
England

9 February 1934

Dear Kapitza,

I was very happy to learn from your kind letter that your troubles with the beautiful and forceful stone carving of Rutherford are now over, and I am very thankful indeed to you and to the artist for your generous offer to present me with a copy of the carving which I and the whole institute shall greet as a most welcome symbol of what physics and I myself personally owe to our great master. We shall find a fitting place for it in the Institute, and I quite agree with your suggesion that the copy should be of the same size and carved in the same stone as the original, as we can always when it is put in place remould the surroundings so as to suit it.

With kindest regards to Mrs. Kapitza and yourself from my wife and me with my heartiest thanks,

N. Bohr'

In 1925 Kapitza was made a Fellow of Trinity College, Cambridge, the educational establishment in which Thomson, Rutherford, Eddington and many other eminent

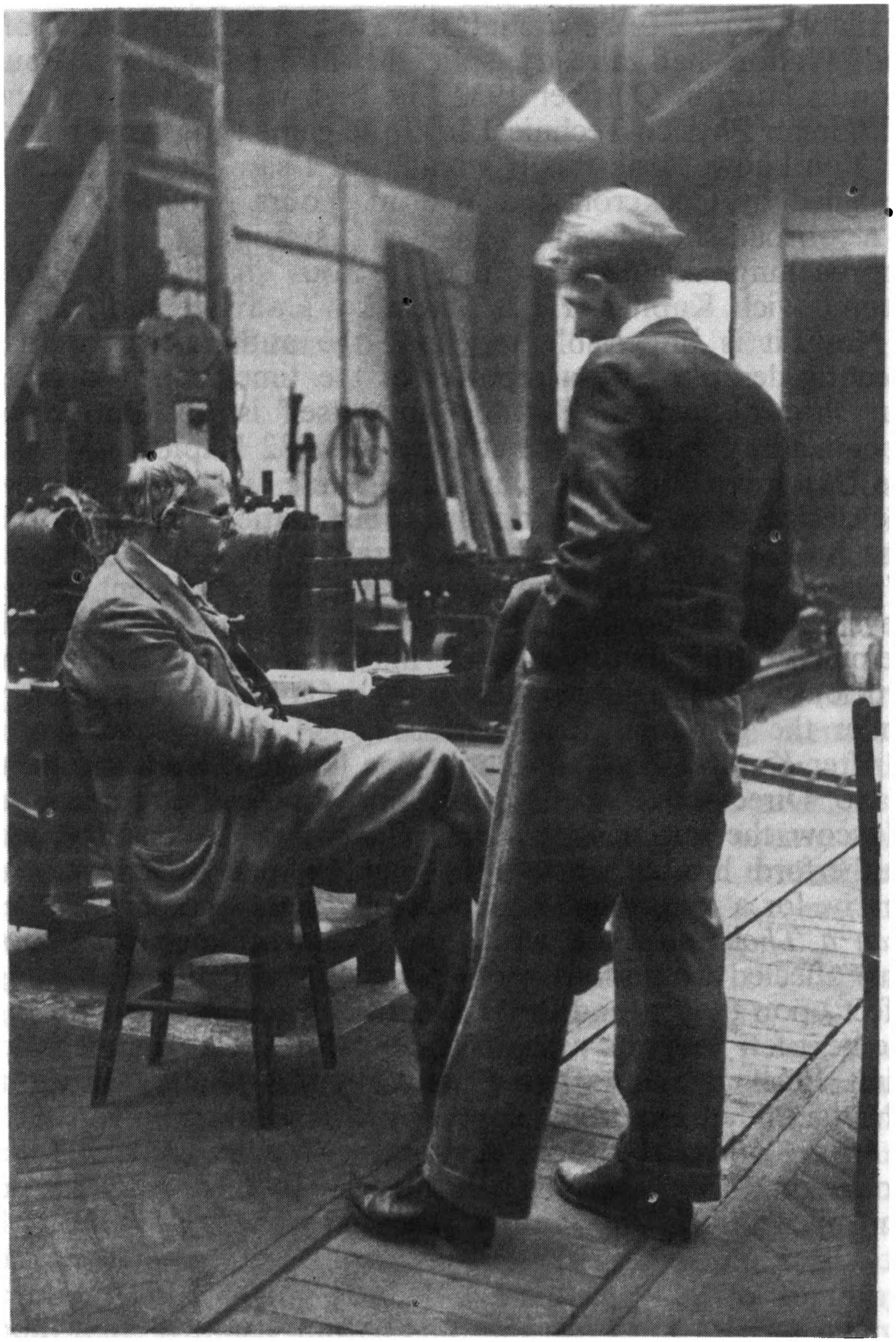
physicists, astronomers and biologists were also Fellows. On Sunday evenings Rutherford would dine at Trinity College together with other well-known scholars and, according to Bohr, discussed a wide variety of subjects with them. Kapitza, who, like Rutherford, took a keen interest in all manifestations of life, also participated in these talks. Bohr recalled: '...Rutherford had a great esteem for his learned colleagues; however, I remember how he once remarked, on our way back from Trinity, that to his mind so-called humanists went a bit too far when expressing pride in their complete ignorance of what happened in between the pressing of a button at their front door and the sounding of a bell in the kitchen.' This phrase contains a humorous comment on the people who while living in the age of science and technology, have no idea of what lies behind the most elementary acts of their daily life.

Together with Rutherford or the aged Thomson Kapitza liked to watch the celebrated Cambridge boat-races on the Cam river. The college teams competed with each other and with those of other universities. Victories were marked in a boisterous and merry style.

Kapitza has been devoted to sport all his life. Pavel Evgenyevich Rubinin, Kapitza's secretary, has told how at his dacha Pyotr Kapitza would take a walk at a pace that few could endure. With his arms folded behind his back Kapitza would cover some 15 kilometres in a circular route at unbelievable speed. And this at the age of almost 80! Pyotr Kapitza is fond of chess and his standard of play is that of a master.

In 1929 Kapitza was elected a Corresponding Member of the USSR Academy of Sciences. Practically every year he visited his homeland to read lectures and conduct tutorials. On 11 November 1932 *Izvestia* carried an interesting paragraph. Observing the style of the times it discussed the work of the Kharkov 'brigade' of physicists (Sinelnikov, Leipunsky and Walter) engaged in the design of a high-voltage proton accelerator. It read:

'After their failure with the pulse generator the team members decided to design a new installation which would provide a lesser voltage potential but a longer discharge. Meanwhile a short notice flashed in the press that British physicists Cockcroft and Walton were designing a similar apparatus. A different standard in the technical facilities


Rutherford with John Cockcroft in P. Kapitza's laboratory, Cambridge, early 1930s

available proved to be crucial: it was reported that Cockcroft and Walton had already split the lithium nucleus. Four months later, in October 1932, the high-voltage team of the Ukrainian Physico-Technical Institute gained the same result.

"You know, Kiril, this is wonderful! I saw the installation designed by Cockcroft and Walton. Yours is better."

A broad-shouldered blue-eyed strapping fellow is approaching Sinelnikov with a vigorous stride. It is Pyotr Leonidovich Kapitza. He is Sinelnikov's adviser and friend.'

Now, it is impossible to check the authenticity of that meeting described by a reporter of the time in a disarming but shrewd manner. But the note itself is not devoid of documentary value. In the summer of 1932 Kapitza did visit the Ukrainian Physico-Technical Institute and did advise on the design there of a high-voltage installation similar to the one built at the Cavendish Laboratory by Cockcroft and Walton. It should be pointed out that the prominent Soviet physicists Kiril Dmitrievich Sinelnikov and Alexander Ilyich Leipunsky (the Institute's staff members mentioned in the article) worked for some time at the Cavendish Laboratory under the guidance of Rutherford.

After Kapitza had left Cambridge for good and had been made Director of the Institute of Physical Problems in Moscow the entire staff of the Cavendish Laboratory and Rutherford himself missed the man, whom they loved so dearly, for a long time. Robert Jungk, the author of *Brighter than a Thousand Suns*, wrote that Kapitza's departure 'not only affected Rutherford very deeply. It also had a disrupting effect upon the Cavendish Laboratory as a whole, and during the next few years its magnificent team began to disintegrate. First Blackett went, then Chadwick and finally Oliphant. They accepted important appointments at other universities.'

After Kapitza the Mond Laboratory was headed by John Cockcroft. Then after the war he was succeeded by David Shoenberg who held the post for many years.

UNDER THE BANNER OF SCIENCE
(Moscow 1934-1941)

Take heart! Take each other by the hand!
And together we'll move ahead
And may our union strengthen and grow
Under the banner of science.

A. Pleshcheev

On his arrival in Moscow in 1934 Kapitza first put up at the Metropol Hotel. He was an unusual citizen and enjoyed, as it were, the status of half-foreigner. This time Kapitza and his wife had come from England by car via Bergen (Norway). Both of his small sons remained with their grandmother in England.

A few paces from the colonnade of the Bolshoi Theatre trams rumbled past, bells ringing. The horns of the 'Renault' taxis screeched sharply and the red 'Leyland' buses, with their high platform and bright copper hand-rails, gave deep honks. *Izvozchiki* (horse-cabs) also crossed the square, the horses scraggy and their drivers in threadbare pre-revolutionary peasant overcoats. There was a constant noise in the square.

This was not only geographically the centre of the capital but also its very nerve centre.

Not far from the Metropol, in 25th October Street that runs from Red Square to Dzerzhinsky Square, there was the editorial office of a popular-science journal. In 1937, a budding journalist, I was asked to write an essay about Kapitza. First of all I had to find the little-known Institute of Physical Problems that had just been built. Judging by the address it was very far from the centre, in the back of beyond, as the saying goes. But no one could do anything about that; Kapitza himself had returned from very far away, from England.

That winter had turned out severe with heavy snowfalls. Past the windows of the bus the snow-covered streets of

Moscow slowly stretched out. It was a long way. Beyond Kaluga Square began the outskirts of Moscow. The bus ran along a deserted Bolshaya Kaluzhskaya Street (now Leninski Prospect).

I passed the former Kaluga Gate. Now it is Gagarin Square, one of the busiest in Moscow. And then? Then it was open space on the edge of which the Institute of Physical Problems was located. The bus crossed the waste ground and stopped at a turning (the stop was aptly called 'Turning'). Getting off the bus I took a few steps backward and soon saw a new two-storey yellow building in front of me. It turned out to be a dwelling house with two-storey apartments for the Institute staff, built in the English manner. The main edifice was behind the building. One could enter it without a pass.

Going up to the first floor and crossing the corridor I entered a spacious room, which was the Institute office, and introduced myself to Kapitza's secretary. He was, perhaps, only a few years older than myself, and not like the other secretaries I met in carrying out my duties: a very young, lean, cultured and lively man with a fine head of fair hair. He grasped the purpose of my visit and sincerely wanted to help me. I recall that while I was in the office the secretary entered Kapitza's study two or three times and returned with shorthand entries in a small note-book. I could not imagine that a man could master shorthand, and was full of respect and envy. Later I learned that Kapitza's first secretary in Moscow was then just starting out in journalism. His name was Oleg Nikolaevich Pisarzhevsky. He subsequently worked for many years with Kapitza, rendering great assistance to the scientist.

Pisarzhevsky was a man of outstanding abilities and a gifted journalist. We were life-long friends from our meeting at the Institute of Physical Problems, until the mournful ceremony at the Central House of Writers in Herzen Street: he passed away leaving fond memories about himself.

Pisarzhevsky proved to be an observant man. All the years that he had been close to Kapitza he studied his chief and in the years of the Great Patriotic War he wrote an article (with A.S. Fedorov) for Kapitza's 50th birthday, published a day later in *Pravda* (10 July 1944).

'Obviously Kapitza knows the secret of tirelessness,' he commented. 'You cannot imagine him without his being engaged in some urgent work. Of course, things are piling up. Kapitza complains: he is director, and experimenter, and lecturer, and on top of all that he has to worry about oxygen [liquefiers] which must be introduced everywhere...

He is capable of running three assistants off their feet at once. When experiments turn out badly he can show the same zeal in modifying them for several hours on end. And while the equipment for an experiment is being prepared he will run up the stairs connecting the laboratory with the "official" premises (accessible to visitors at any time), and dictate a small chapter from his new book during a pause in the experiments.

If he looks drowsy or phlegmatic it means he is most thoroughly considering some new idea. And after this labour of thought has been completed he rouses himself and makes for the workshop where one of his assistants – a mechanic – has been busy for several days with a long-planned apparatus. The things the mechanic has been working on during the last day or two will have to be done all over again. The mechanic momentarily loses any interest in what he was doing. But that happens for no special reason – just a sudden surge of weariness. It is hard for one to clamber up a hill and then go downhill at once. In a minute he will cast an appreciative glance at the new sketch outlined by Kapitza on the bottom of a tobacco box.'

The above excerpt is a lively sketch showing, as far as the scope of a newspaper article allowed, the character of Kapitza as a researcher and the impression he gave in a working atmosphere.

When I first entered Kapitza's study I found myself in a large gallery of photo portraits hanging on all the walls. Pyotr Leonidovich received me graciously and fixed the day when he could show me round the laboratory where there were installations for obtaining strong magnetic fields and low temperatures.

When I was in the office I noticed a short, very skinny young man with close-cropped, black hair. He wore a sports jacket which was unbuttoned. He rushed in, exchanged a few words with Pisarzhevsky, took a paper and went away. I met this man several times on my occasional visits to the Institute, but did not know who he was for a long time. Only

when I had to visit Professor Shalnikov did I learn, to my great surprise, that the fellow in the jacket was Alexander Iosifovich Shalnikov himself, one of the first scientists taken on to the staff of the Institute of Physical Problems. A. I. Shalnikov has changed very little since I saw him first in 1937; he still runs through the Institute with a leather jacket on, bare-headed, his hair having turned white. Quick, always awfully busy, catching the meaning of everything at once he is engrossed in his experiments and his work in the laboratory.

...I left the Institute and made for the bus stop. The place looked quiet and deserted. The city seemed to be very far away. Later I learned that Kapitza liked the place very much, and that he thought it ideal for his Institute: the building was some 80 metres away from the tram lines, ground vibrations were reduced to a minimum, and the bus service was very infrequent – I had to wait for the bus for about an hour.

The site for the construction of the Institute was chosen where the botanical gardens of the USSR Academy of Sciences were to be laid out. The institute was thus supposed to be isolated for ever from traffic noise and the inevitable electric disturbances that would affect the operation of very sensitive instruments. But the plans to lay out the botanical gardens there were later rejected and the place around the institute turned into a vast development area with heavy traffic. Perfecting the laboratory and experimental equipment, and using reliable screening facilities, researchers learned to properly shield their experiments from the disturbances occurring in a large city. The quiet place where the institute was first built is now one of the busiest in Moscow.

The first thing I wanted to learn when I came to Kapitza was how they managed without a pass system. It turned out that the working (laboratory) part of the building was on the ground floor. The first floor was intended for administrative and other purposes: book-keeping, lecture rooms and the director's study. No visitors could get straight to the ground floor laboratories since they had first to enter the office upstairs, from which the only way to the ground floor was through the director's study. As for the research workers, they could reach the director's study from their own rooms via an internal staircase. Many years have passed, many things have changed, and the system of doing without passes

has also gone. Incidentally, now visitors can also have free access to the Institute's office room, the director's study and the studies of his deputies, the library and the theoretical department.

Kapitza returned from England late in 1934. The Institute was founded by a government decree dated 28 December 1934. The construction of the Institute began early in 1935. The name was suggested by Kapitza. 'Its somewhat unusual name', he explained, 'was intended to indicate that the institute would not deal with any specific realm of knowledge, but would carry out research in a variety of fields whose nature and scope would be determined by the scientists working there. In other words, the institute was to engage in pure rather than in applied science.' This explanation, offered at the meeting of the Physics Group of the Academy of Sciences on 15 March 1937, was rather risky at the beginning, and, perhaps, was not clear to everyone: the term 'pure science' had then been rejected, since it was believed to imply researches that would never be used by the national economy. 'I use the somewhat unpopular expression 'pure science', Kapitza went on, 'for lack of a substitute. The term "theoretical science" was proposed, but in fact every science is theoretical. In essence, "pure science" or *reine Wissenschaft* is a well-established expression. The only difference between pure and applied science is that applied science deals with problems arising from daily life, while pure science leads to applicable results: for in one way or another scientific knowledge always finds an application in everyday life, even though it may be difficult to foresee how or when this will happen.'

All his life Kapitza has been convinced that any scientific discovery may sooner or later be applicable, and this conviction must have been fully justified in his own case. Late in 1971 I asked Pyotr Leonidovich whether he thought it was worthwhile to invest enormous sums into thermonuclear research, whether mankind would need such a tremendous amount of energy. Kapitza replied that thermonuclear research should be promoted in every way, that any scientific discovery would always lead to applicable results.

The plan of the Institute developed by Pyotr Leonidovich met all the demands made on a scientific-research centre.

According to Kapitza an attempt was made to make it as perfect and advanced as possible. 'I think this aim has been achieved and the institute can be considered one of the foremost not only in the Soviet Union, but also in Europe', he pointed out.

By the decision of the Soviet government the main items of equipment were purchased from the Royal Society; before this they had been in the Mond Laboratory in Cambridge. Representatives of the Society approached Rutherford on the question of selling the equipment of the Mond Laboratory. Rutherford is said to have replied in an angry voice: 'These machines cannot work without Kapitza, and Kapitza cannot work without them.' The problem was resolved and the equipment was shipped to Moscow.

The construction of the Institute made slow progress. In one of his letters Kapitza wrote: 'Things are going slowly and badly. I have not lost heart as yet. I want to do all I can here to carry on my former work.'

For three years while the institute was being built Kapitza had no laboratory of his own. 'During those years', he recalls, 'the only scientist outside the USSR with whom I corresponded was Rutherford. At least once every two months he wrote me long letters which I greatly valued. In these letters he described life in Cambridge, spoke of his successes in science and his school's achievements, wrote about himself, joked and gave me advice, and invariably cheered me up in my difficult position. He understood that my chief desire was to return to my scientific work as soon as possible, which had been so abruptly interrupted. It is no secret that it was largely due to his intervention and help that I was able to get my scientific equipment from the Mond Laboratory, so that three years later I could again resume my work in the field of low-temperature physics.'

I would like to cite a few excerpts from Rutherford's letters to Kapitza.

On 21 November 1935 he wrote:

'I am inclined to give you a little advice, even though it may not be necessary. I think it will be important for you to get down to work on the installation of the laboratory as soon as possible, and try to train your assistants to be useful. I think you will find many of your troubles will fall from you when you are hard at work again... I dare say you will think I do not understand the situation, but I am sure that the chances of your

On the site of the future Institute of Physical Problems, Moscow 1935. Kapitza with his secretary Shaposhnikov

happiness in the future depend on your keeping your nose to the grindstone in the laboratory. Too much introspection is bad for anybody!'

On 15 May 1936 he wrote:

'This term I have been busier than I have ever been, but as you know my temper has improved during recent years, and I am not aware that anyone has suffered from it for the last few weeks! Get down to some research even though it may not be of an epoch-making kind as soon as you can and you will feel happier. The harder the work the less time you will have for other troubles. As you know, "a reasonable number of fleas is good for a dog"–but I expect you feel you have more than the average number!...'

The last letter was dated 9 October 1937. He wrote in detail about his proposed journey to India. In the last part of the letter he said: '...I am glad to say that I am feeling physically pretty fit, but I wish that life was not quite so strenuous in term time.'

Ten days later Rutherford passed away.

In the obituary published in *Izvestia* Kapitza compared Rutherford with Faraday, as an experimental physicist endowed with exceptional intuition. According to Kapitza, this intuition had led Rutherford to the experiments by means of which he found a simple and clear solution to the most complicated issues. 'In physics, as in any other science', wrote Pyotr Leonidovich, 'there are a number of basic problems the solutions of which point, as it were, to the future trends of research. Not many scientists have managed to set more than one such trend; Rutherford, like Faraday, set a few.'

In his address delivered before the Royal Society on 17 May 1966, 32 years after he had left Cambridge, Kapitza said: 'To me the death of Rutherford was not only the loss of a teacher and friend. To me, as for a number of scientists, it was also the end of a whole epoch in science.'

On 20 August 1971 Kapitza, Feather and other disciples of Rutherford, who had come to Moscow to attend the colloquium in memory of their great teacher, could see him again in a film shot in the 1930s. In the film Rutherford narrated in level tones the achievements of nuclear physics. During the showing an uncommon silence reigned in the hall. Even those who did not understand English listened to every word with bated breath.

Rutherford's mandate to Kapitza to get down to research as soon as possible could not be fulfilled right away. The construction of the institute was dragging on. There was a shortage of apparatus, materials and precision lathes. Kapitza would not agree to any simplifications.

It has already been said that the laboratory part of the building was entirely on the ground floor: this is essential in working with liquid helium and hydrogen, which have to be kept in the laboratory, as both safety and convenience demand that these activities be concentrated on the same floor. The ground floor, was, moreover, much quieter as regards all kinds of vibrations and it also contained a hall which accommodated the liquefaction installation. There was no other storey above this part of the building, which had lightweight roofing in order to minimize the effect of any accidental explosion.

Part of the basement was occupied by the boiler-room, while another part was reserved for experiments with highly sensitive apparatus. One room was lined with barium stucco for X-ray experiments, and another room was intended for spectroscopic work.

The institute was planned as a self-contained unit, with its own workshops, libraries, and so on. Kapitza thought that this was only a temporary arrangement, since the institute must eventually become an integral part of the central system of the Academy of Sciences. But for those who knew the Institute of Physical Problems well it is clear that the Institute's numerous facilities designed by Kapitza have proved indispensable. Up to the present, the most original items of apparatus are built in the workshops. A large, first-class library has been collected. Pyotr Leonidovich receives books from many countries and practically all of them can be found at the Institute library.

The Kapitzas lived in the Institute grounds in a cottage consisting of several rooms. From the hall a staircase led to the rooms upstairs. On the ground floor, in a spacious sitting-room there were glass cases where a beautiful collection of *Khokhloma* (traditional lacquered wooden toys) was kept. Kapitza's children – Sergei and Andrei – were of school age then and an English tutoress Silvia lived with the family. Later she married a Soviet scientist.

Kapitza resumed his research in the field of superstrong magnetic fields with the equipment brought to Moscow from

the Mond Laboratory. The Cambridge staff members who had come on a visit to Moscow – Pearson (mechanic) and Lowerman (laboratory assistant) – participated in the experiments. This work took several years and Kapitza considered it to be very important. In 1943, in his report at the meeting of the Presidium of the USSR Academy of Sciences, Pyotr Leonidovich said that in his opinion there were three basic directions in the field of physics: research in the areas of low temperatures, the atomic nucleus, and the solid state. 'Our institute', Kapitza stated, 'is presently engaged in the study of the phenomena occurring at low temperatures, near absolute zero. Let me note that in recent years this has been one of the most rapidly developing fields of physics, and many new and fundamental discoveries can be expected within it.'

Continuing the work he had started at the Mond Laboratory on creating an advanced technique for obtaining liquid helium, Kapitza built his first turbo-expander, i.e. a helium liquefier of a turbine type. Before getting down to the design of the liquefier Pyotr Leonidovich conducted numerous experiments and investigated the operation of high-speed turbines. Kapitza's first turbo-expander was already very efficient. His turbo-expanders made it possible to design low-pressure liquefiers which used compact highly efficient turbo-compressors instead of piston compressors. Kapitza's turbo-expanders turned out to be very efficient in installations producing large quantities of commercial gaseous oxygen. Kapitza's original turbo-liquefiers necessitated a revision in the principles governing the refrigeration cycles used to liquefy and separate gases. This revision has essentially changed the development of the technology universally employed to obtain large quantities of oxygen.

In 1938 Kapitza, then a Corresponding Member, was nominated for full membership of the USSR Academy of Sciences (now located in Moscow). In their report to the Academy supporting this nomination four Soviet scientists – Academicians S. I. Vavilov, A. N. Bakh, A. N. Frumkin and A. M. Terpigorev – expressed a very high opinion of Kapitza's scientific work. 'Without a doubt, Kapitza is one of the most brilliant experimental physicists in

our country. P. Kapitza began his scientific work at the Leningrad Physico-Technical Institute and immediately displayed exceptional aptitude, having designed, among other things, an apparatus for measuring and determining the magnetic moment of the atom (the experiment was in fact carried out by Stern and Gerlach). In 1921 Kapitza was sent on a scientific mission to England where he worked for 14 years, first under Rutherford's supervision and then as a director of a separate laboratory. In these years Kapitza's works placed him among the world's most outstanding experimental physicists... We believe that by his scientific achievements in the field of physics P. L. Kapitza is an eminently desirable member to have within the Academy of Sciences.'

The election of candidates for full membership of the Academy of Sciences of the USSR took place on 24 January 1939 under the chairmanship of Academician Alexander E. Fersman, Secretary of the Academy's Department of Mathematical and Natural Sciences. The presentation report was made by Academician Sergei Vavilov. Kapitza was elected unanimously: all the 35 academicians present at the meeting voted in his favour.

Now there is one more academician in Kapitza's family: his younger son Andrei Petrovich is a Corresponding Member of the USSR Academy of Sciences, who has participated in several Soviet Antarctic expeditions. For a long time he was the chairman of the presidium of the Far-Eastern scientific centre of the Academy and lived with his wife and children in Vladivostok.

Pyotr Leonidovich once told me that in their family four generations have been associated with the Academy of Sciences. Andrei and Sergei's great-grandfather, I. I. Stebnitsky, was a Corresponding Member of the Imperial Russian Academy of Sciences; their grandfather (A. N. Krylov) and father are academicians; and, lastly, Andrei himself is a Corresponding Member of the USSR Academy of Sciences. Kapitza thinks that such 'academic continuity' is very rare and from Kapitza's tone one can guess he is pleased to feel himself a link in this unusual 'academic chain'. (Perhaps he hopes someone from the next generation of the Kapitzas, i.e. his grandchildren, might obtain a well-deserved, 'hereditary' place in the Academy of Sciences.) His elder son Sergei Petrovich Kapitza is now

a Professor, D. Sc. (Physics and Mathematics), and a research associate of the Institute of Physical Problems, and he has a number of works to his credit. He has three children. Soviet television viewers know him as the presenter of the popular science programme 'The obvious – and the incredible'.

The collective of researchers headed by Kapitza possessed one invaluable trait which has helped them to work well: a sense of humour. A. I. Shalnikov, Member of the USSR Academy of Sciences, has been and still is one of the 'wittiest' scientists in the Institute.

In 1938, the Institute's wall-newspaper carried a sketch by Shalnikov, which was a sharp parody of a meeting of Kapitza's seminar. Many years later, on 15 October 1975, *Literaturnaya Gazeta* carried an abridged reprint of it; the parody was as topical as ever. Of course, the participants of the above seminar had grown much older: many of them became prominent scientists, and some others – Academician L. Landau, Corresponding Member of the Academy of Sciences P. G. Strelkov, and the Institute's Deputy Director O. A. Stetskaya – had passed away.

The task of the seminar, organized by Kapitza soon after the Institute of Physical Problems was opened, was seen as keeping scientific researchers and at the same time the scientific community of Moscow up-to-date on major advances and problems in physics. The seminar is still functioning. Here you can always meet scientists from other institutes, postgraduates and students. Generally, between 70 and 80 invitations are sent out to 'outsiders'. Many attend Kapitza's seminar without invitations; this is not prohibited, if only there is enough room for everyone.

The prototype of the seminar was the one in which young Kapitza participated in Petrograd. The problems discussed before a wide audience are not only of informational significance: they stimulate fresh research and give birth to new ideas.

At the turn of the century scientific seminars were not as important as they are today. The first seminar of this kind in Russia was organized by A. F. Ioffe. In Cambridge University there was then nothing of the kind. Soon after he joined the Cavendish Laboratory, Kapitza set up the seminar we have

Kapitza conducts an experiment with his assistant S. I. Filimonov, 1939

already mentioned. It mainly attracted Rutherford's staff members and research students who regularly met as the 'Kapitza club' at whose sessions reports were made on topical problems in physics.

Kapitza's seminar in Moscow became much broader both in membership and the issues discussed. The institute's assembly-hall would often be too small to accommodate all those wishing to attend the seminar and listen to a report by Kapitza, or by some other outstanding scientist invited from another city or country.

Once, on my way to Pyotr Kapitza's seminar, I saw a big crowd of young people in front of the locked gates of the Institute. I noticed a hastily written announcement on the iron fence: 'Sorry, the hall is full'. I barely managed to get into the institute. The assembly-hall was indeed filled to overflowing. All were waiting impatiently for Kapitza's report on ecological problems.

If you traced all the topics that have been discussed at Kapitza's seminars they alone would give you an idea of the

development of physics over the past few decades. As long ago as before the war Niels Bohr reported on nuclear physics at the seminar. At the time of intense thermonuclear investigations using Ogra machines a report at the seminar was made by Professor I. N. Golovin, I. V. Kurchatov's close associate and a specialist in this field. Several years ago the participants of the seminar listened to a report by Nobel Prize winner Paul Dirac, the eminent British theoretical physicist, who spoke about the latest achievements in cosmogony.

Up to the present, Kapitza's seminar is of great significance for theoretical and experimental physicists. It constantly keeps them abreast of the major and most interesting problems of science.

So A. I. Shalnikov wrote his amusing satire of a meeting of the seminar, exaggerating and drawing caricatures, as is customary for a satirist. But physicists appreciate jokes and are inclined to think that a joke helps to relieve the frustration that waylays the scientist. Below follows the abridged text of the parody.

You don't come here to smoke and eat: This is where serious scientists meet

Kapitza's study. On the walls the portraits of former celebrities look bored. Seated in the armchairs are the weary originals for the celebrities of the future. Candidate-celebrities are discussing purely private matters in dismal low voices.

The clock is ticking with a sharp clatter, which reminds one of a lady's steps in wooden sandals: it shows three minutes past seven. Suddenly one hears a powerful tramp of feet on the staircase, and the next moment Pyotr Leonidovich bursts into his study. Ignoring those present he stares at the astronomical clock and trips over the edge of the carpet.

'This clock is fast,' he says, 'I make it only one and a half minutes to seven.'

In the usual playful tone Landau adopts when talking with unacquainted women or delivering scientific reports at the department of physical and mathematical sciences he disrespectfully rejoins: 'The clock is almost right.'

He checks his wrist watch and adds in an even more disrespectful way, 'The clock is wrong. It's actually a minute and a half slow. It's slow.'

Taking advantage of his rights as chairman Kapitza cuts short discussion about the clock.

'Well, what's on today?' he asks Strelkov.

Strelkov nervously adjusts his sleeves and formally announces the following:

'The speaker today is Nikolai Evgenyevich. Nikolai Evgenyevich has prepared an extensive review of the latest works on superconductivity, Pyotr Leonidovich...'

Says Kapitza: 'Well, if no one, er...we might as well start. Nikolai Alexandrovich, please go ahead.'

Nikolai Evgenyevich Alekseevsky goes to the blackboard. He is worried. The reason for his being worried is not obvious and only gradually becomes clear. He has a bundle of journals in his hands. He is a hard worker and a total abstainer, but he is wearing such an awful expression that the only alternatives are that he did not get to sleep for four or five days, or just had no time to sober up after a drinking-bout the day before.

The audience makes itself as comfortable as possible, anticipating the enjoyment of the next two hours. Only smartly dressed Olga Alexeevna in her sparkling white collar flashes at everyone the indignant glance of a tutoress in an awkward position: the children are misbehaving but you feel embarrassed to tell them off... Kapitza looks vacantly out of the window. One might assume that he has absolutely nothing to do with what is going on. A contrast to Olga Alekseevna, who is all ears. Landau turns his back on the speaker. He behaves in his usual independent and easy manner.

Strelkov is absorbed in the seminar journal, engraving the names of those present to be remembered by posterity. Every now and then he winks to himself and after completing his writing nervously pulls out a cigarette. He has no light. With his cigarette he reaches out to Pyotr Leonidovich who, no longer in deep thought, is casting a vacant glance at him. Strelkov smiles sweetly still holding out his cigarette; then his smile becomes unbearably enchanting. This mute scene lasts about a minute and a half. Then Kapitza guesses that Strelkov wants a cigarette-lighter and gives him a light. To make the most of the situation Kapitza digs around in his pockets, extracting two, three, four and, perhaps, five pipes. Having chosen a suitable one with extreme fastidiousness, he frenziedly beats it against the mirror surface of the polished desk. The burned out ashes rise upward just as they do during an eruption of the Krakatoa volcano. Olga Alekseevna is watching all this with silent and humble suffering.

Alekseevsky is nervously pacing up and down in front of the blackboard and going through the journals. His face reflects the hectic process of his intellectual activity. He opens and shuts his mouth several times but does not yet utter a sound. Shoenberg who was wise enough to occupy the softest armchair sinks into a sweet sleep. An extinguished cigarette sticks out of the corner of his mouth. Livshits casts a longing and expectant look at the door. Shalnikov quietly nudges Shoenberg. He is nurturing a hellish plan of getting Shoenberg to wake up and, taking advantage of his relative pliability, to wheedle a cigarette out of him...

Unexpectedly, certain sounds begin to be heard from the blackboard... It turns out that Alekseevsky has already been giving his report for several minutes. But feeling somewhat confused at the beginning he expresses himself by means of infrasounds only, gradually raising the volume. So far there is only sufficient evidence to ascertain the fact that, apart from the striking of the clock, Nikolai Evgenyevich is the source of the indistinct sounds uttered in the study. One cannot understand anything. One can only assess in purely qualitative terms the speaker's bass which might be envied by Shalyapin himself.

'Well, er, ... er ...', mumbles Nikolai Evgenyevich.

Then sounds begin to merge into words. Some of them, such as London, Meissner, tantalum can even be distinguished...

Addressing Strelkov he tells the reason for his anxiety.

'Well, ... er...er...er, Pyotr Georgievich, well, ...er...er. The material I've got will take only five minutes to report. The work is very short...'

'The work is comprehensive. You must have not had the time to read it,' says Shalnikov turning from a lamb into a roaring lion because of the absence of a cigarette.

Nikolai Evgenyevich stops, gives Shalnikov a withering look and continues to mumble. The already familiar words now sound very clearly: London, Meissner, tantalum...

The door opens and the tea-lady enters with a tray in her arms, attracting the attention of everybody except Pyotr Leonidovich who, realizing at once that there are neither apples nor mandarins on the tray, continues to observe nature through the window.

Nikolai Evgenyevich is drawing some squiggle on the blackboard, which is called a curve in this shrine of science.

Shalnikov has been put in a defiant and ostentatious frame of mind. There is no cigarette. At such moments he is inclined to shake the world to its foundations, and is capable of wronging a child, of being rude to the deputy director or of robbing a church. He interrupts the quiet and peaceful procedure of the seminar. In a spiteful voice he addresses Alekseevsky and asks what is laid off on the axes.

'Pressure...', mumbles Nikolai Yevgenyevich, 'no, temperature. That is, yes, pressure...'

Meanwhile E. M. Livshits, senior research associate, D. Sc. (Physics and Mathematics), becomes the arena of opposing passions. On the one hand, he is driven by the professional meticulousness of a theorist-casuist, and, on the other hand, he cannot tear himself away from contemplating the dish with sandwiches. At last scientific consciousness wins in this titanic contest.

'And on the other axis?' he asks.

There is nothing on the other axis. It is designed so that in the other world you could stick on it the people who ask pointless questions – Alekseevsky wants to say, but instead he forces out:

'Well,...er...er...er... Thermal conductivity...'

Now you cannot easily get rid of the damned curve; you will have to show it through the epidiascope. Alekseevsky is looking with envy and sorrow at the sandwiches melting away on the dish...

Alekseevsky casts a pleading look at Livshits but he is inflexible. He did his duty and his conscience is clear. He firmly takes the last sandwich. In a cheerless voice Alekseevsky begins to mutter something dealing with certain contaminations.

Kapitza interrupts him:

'Where was this work done?'

'In Oxford. Well, I mean in Toronto... Well, certainly in Oxford...'

'And who received the credit for it?'

'Well, ...er...er...er..., Simon...'

'As usual this..., well, what's his name? You say Maclennan is doing very messy work. All his works are full of garbage...'

Olga Alexeevna grows red, and makes a movement to leave the hall, but a sense of duty makes her stay.

'He is a very good physicist,' Kapitza goes on, 'but that garbage...'

At that moment the sleeping Shoenberg (from whose mouth Shalnikov has pulled an extinguished cigarette) wakes up.

While they are trying to clear up what sort of alum – iron, chrome or aluminium – was used by Simon, Maclennan or Allen, Shoenberg becomes fully conscious and resolutely turns to Shalnikov:

'Didn't you see my cigarette?'

'Let me listen,' says Shalnikov, pretending he is listening attentively to Alekseevsky's mumbling.

'It's an expensive cigarette,' Shoenberg says, 'I paid one rouble and 30 kopecks for 25 cigarettes.'

'You ought to be ashamed of yourself, Shoenberg. You smoked it long ago...'

'You're wrong. I couldn't have smoked it. I measured it at the last seminar – one cigarette and another half of its size lasted me the entire two hours. They are very good and expensive cigarettes.'

'Better chain up your cigarettes,' replies Shalnikov.

Having mumbled slowly something intended to round up the whole discussion, Alekseevsky turns to Kapitza:

'Well, that is about all I was going to say, Pyotr Leonidovich.'

'A very interesting study,' utters Kapitza getting his pipe going. 'But it is so full of garbage... Who is the next one?'

'Today's speaker, Pyotr Leonidovich, ... well, Pyotr Leonidovich, only Nikolai Evgenyevich was supposed to speak,' Strelkov prompts ingratiatingly.

'We've got another two and a half hours left, I mean, three and a half', says Kapitza.

Looking at the clock Landau remarks disrespectfully:

'We've got 47 minutes to go.'

'That's it, 57 minutes are left. Maybe, well,..., er... Deryagin will speak now', says Kapitza gazing fixedly at Mikhail Mikhailovich Kusakov. 'In general, seminars are very useful. You can hear many interesting things there which it would never occur to you to read... Even in summer it is not worthwhile to stop holding seminars. What's your idea, Alexander Iosifovich? So, perhaps', he goes on looking at Kusakov, 'comrade Deryagin would report on his work...'

Kusakov says gloomily:

'My name is Kusakov.'

'That's what I'm saying – Deryagin.'

Kusakov retorts even more gloomily:

'My name is Kusakov.'

'What?'

'My name is Kusakov.'

'What? Why not Deryagin?...

There is a general confusion, as it is difficult to give an exhaustive and

satisfactory answer to Kapitza's question. However, Kapitza finds a way out by making a dexterous move:

'Well, if there is nothing new today we could close the sitting. Perhaps, next time we shall invite, what's his name, ... Leontovich... Let him tell us about the diaphragm.'

While those present were guessing whom Kapitza meant by the name of Leontovich (it turned out to be Zelmanov) Shalnikov was finishing Shoenberg's butt and was delighted. In such a mood he would one day discover the secret of superconductivity, speak well about the administration, or pet a child.

'Do you remember, Pyotr Leonidovich,' he said, 'you said once that in summer reports should be less frequent?'

'Less frequent?' Kapitza asked.

He again divorced himself from his thoughts and took his eyes off the window. There was something he liked about these words.

'Less frequent... Well, of course, why meetings in summer? In summer one should be out-of-doors rather than in conference. I've always been saying this but they would not agree with me. From now on we shall meet twice a week at most.'

'I think you meant once in two weeks?'

'That's it–twice a week. Perhaps, no sittings whatever in the summer? How about those present?'

The audience reacted with a shade of enthusiasm. All, except Olga Alexeevna, who was smiling tactfully. She could not openly approve of the idea which could hardly be interpreted as one aimed at improving labour discipline. But she did not think it reasonable to take up an argument on this delicate question in the presence of outsiders.

'Very well, then!' said Pyotr Leonidovich. 'So, I declare the sitting closed for the summer.'

Kapitza designed a machine to produce liquid air and suggested that it be used for industrial purposes. A competent commission approved the prototype built at the Institute of Physical Problems. One of the plants set up a design office and a special shop which were entirely preoccupied with Kapitza's installations.

For several years Kapitza was engrossed in the work on designing a liquefaction technique. After an installation for the production of liquid air had been built Pyotr Leonidovich got down to the design of an oxygen liquefier. The Institute's workshops now looked like a factory floor. Within a year and a half several oxygen liquefiers which the Institute later handed over to industry were manufactured.

The work on building liquefiers did not hamper low-temperature investigations which resulted in a major scientific breakthrough in 1937, namely, the discovery of

superfluidity of helium II. Kapitza wrote then: 'The study of liquid helium and its properties is part of the physics of very low temperatures. It is one of the branches of physics where one attempts to explore natural phenomena under extreme conditions. We can most readily expect discoveries of interesting phenomena when we study nature in the most extreme conditions she permits, such as in strong magnetic fields, high pressures, high electric voltages, and so on, and also in the region of extreme cold when we approach absolute zero (– 273.15 °C). We can also look forward to observing new phenomena – properties of nature which under normal conditions either escape observation, or simply do not occur. The temperature region near absolute zero is, in that respect, particularly interesting. The investigations of the last decade have clearly confirmed this point of view.'

According to the prominent theoretical physicist É. M. Livshits, the development of low-temperature physics was guided by the investigation of two 'superphenomena' – superconductivity and superfluidity. The former was discovered by Kamerlingh-Onnes three years after he had succeeded in liquefying helium, the latter by Kapitza 30 years after the discovery of superconductivity.

Early in 1938 the English journal *Nature* carried Kapitza's article on the determination of viscosity of liquid helium flowing through capillaries or narrow gaps between plates. The history of this article is somewhat unusual. Kapitza did not send the article directly to the editors of *Nature* but instead to John Cockcroft in Cambridge asking him to use his influence and publish it as soon as possible. Cockcroft had it published within a short time. The same issue of the journal carried an article by the English physicists Allen and Misener, who worked in the Mond Laboratory, which Cockcroft then directed. The article described similar experiments. In both cases the results of the experiments coincided, which was the reason why Kapitza had lost the priority of the discovery. Unlike all the other known gases liquid helium does not turn into a solid even at temperatures that are only a few thousandths of a degree from absolute zero. It can be made solid only under a pressure of at least 25 atmospheres. Helium turns into a liquid at 4.2 K, i.e. at – 269 °C. If we lower the temperature to 2.2 K, liquid helium will undergo another change; in this case one usually says that helium I becomes helium II.

The Dutch physicists W. and A. Keesom (father and daughter) were the first to show experimentally that helium II is the best of the known heat conductors. It was now possible to explain why the boiling surface of liquid helium when cooled to 2.2 K suddenly ceases to boil and becomes smooth: because of rapid heat transfer from the vessel's walls steam bubbles inherent in boiling are not formed on them.

Kapitza repeated Keesoms' experiment under slightly altered conditions and found an even greater thermal conductivity of helium II. To explain such a phenomenon on the basis of generally accepted ideas of the mechanism of heat conduction proved to be impossible. Kapitza thought that convection heat transfer might be the cause in this case. He assumed that in helium II there easily arose liquid flows and that this was why it possessed such a great ability to transfer heat. Kapitza calculated that intense heat transfer in liquid helium could only be effected through convection flows which must flow with extreme ease. He, therefore, suggested that at very low temperatures helium II is a liquid with extraordinary fluidity, i.e. a liquid without viscosity.

Physicists are well aware of the very delicate and subtle experiments by means of which Kapitza measured the viscosity of helium II. His calculations showed that the viscosity of liquid helium is roughly 1/10,000 that of liquid hydrogen, the most mobile of the known substances. Liquid helium thus turned out to be more than a thousand million times more fluid than water.

On the basis of his experiments Kapitza drew a bold conclusion: liquid helium flows as a liquid which has no viscosity. He called this property of helium II superfluidity.

In subsequent years Pyotr Kapitza continued to explore superfluidity and discovered some amazing properties of helium II. One of Kapitza's finest experiments was as follows: in front of the free end of a capillary tube filled with, and submerged in, liquid helium a light vane was suspended. On being heated the escaping liquid struck against the vane which was thus deflected. The experiment proved that heat transfer in helium is due to the motion occurring within it. But the motion was quite paradoxical: the liquid escaped from the opening and deflected the vane but the amount of the liquid in the vessel did not change, and it continued to be full.

Kapitza provided convincing evidence that at temperatures

below 2.2 K liquid helium consists of two components – superfluid and normal. The superfluid component has zero entropy, i.e. in this respect it is a liquid at absolute zero. The phenomenon of superfluidity has attracted the attention of many Soviet and foreign theoretical and experimental physicists. Kapitza's discovery of superfluidity is still a source of new investigations. It forms the basis of the theory of superfluidity of liquid helium created by Lev Landau. Using the principles of quantum mechanics Landau explained why helium II has such peculiar properties.

E. M. Livshits, a Member of the USSR Academy of Sciences, wrote about Landau's physical picture of superfluidity. The generally accepted description of motion, namely, indication of velocity in each point of the flow turns out to be absolutely incorrect for the motion of helium II, the first quantum liquid that physicists have discovered in nature. To describe the motion of helium II it is necessary to indicate not one but two velocities for each point of the flow. This can be visualized if helium II is considered, as it were, a mixture of two liquids, two components capable of moving independently one through another without any interaction.

'But in fact there exists only one liquid', E. M. Livshits remarks, 'and it should be stressed that this "twoliquid" model of helium II is merely a convenient description of the phenomena occurring within it. As any other description of quantum phenomena in classical terms it is not quite adequate, which is entirely natural if one recalls that our visual notions reflect what we deal with in everyday life, whereas quantum phenomena generally manifest only in the microcosm which is beyond our direct perception.'

Both motions occurring in liquid helium have different properties. One of them occurs as if one component had no viscosity at all. Landau called it the superfluid component. The other component moves as an ordinary viscous liquid. It is called the normal component. The basic difference between these two kinds of motion of the components in helium II is that the normal component transfers heat when in motion, whereas the motion of the superfluid component is not accompanied by heat transfer.

'In a sense', writes Livshits, 'one could say that the normal component is the heat proper which becomes in helium II an entity in its own right separating itself from the bulk of the

liquid and acquiring, as it were, an ability to move about against some "background" which is at absolute zero. It is worthwhile considering this picture and trying to understand how very different it is from the common idea about heat as a chaotic motion of atoms of substances, inseparable from its entire mass.' Landau explored many phenomena linked with superfluidity. He gave a detailed description of all the known properties of helium II and predicted some absolutely new phenomena later discovered experimentally. This can be exemplified by Landau's conclusion that, apart from ordinary sound, in helium II there exist oscillations of another type which he called 'second sound'. Landau showed that contrary to usual (first) sound which is largely oscillations of pressure in 'second sound' the main oscillations are those of temperature. By using the idea of the experiments suggested by E. M. Livshits, Kapitza's disciple A. P. Peshkov experimentally discovered 'second sound' in full quantitative agreement with Landau's theory.

In the Soviet Union superfluidity has been explored by many scientists, including Academicians I. Ya. Pomeranchuk and E. M. Livshits, Corresponding Members of the USSR Academy of Sciences A. A. Abrikosov, I. M. Khalatnikov, and Academician N. I. Bogolyubov. The phenomenon of superfluidity discovered by P. L. Kapitza has become a topic of research for several decades to come, and this research has led to numerous wonderful results.

Not so long ago physicists obtained a new quantum liquid – the liquid isotope of helium ^3He (natural helium has two isotopes – ^4He and ^3He). From the theoretical point of view quantum liquid ^3He is of great interest. The theory of this liquid was developed by Landau in 1956–1957. In 1962 Landau was awarded the Nobel Prize in physics for his 'pioneering research in the theory of condensed media, especially of liquid helium'.

Fate had a tragic end in store for Landau: he was injured in a car accident and after a long battle for survival died at the age of 60. Kapitza was very closely involved in the efforts to save Landau's life. When oedema of the brain and of the whole body developed physicists were in a state of deep despair. The doctors knew that abroad there was a medicine which in such cases could sometimes help to save a patient's life. Having heard about it Kapitza at once sent cables to his friends Patrick Blackett, Pierre Biquard and Ogge Bohr in

London, Paris, and Copenhagen respectively to send the necessary medicine as quickly as possible. Niels Bohr sent a medicine right away but, regrettably, not the one which was needed. Biquard, having failed to get the required medicine in Paris, called up František Šorm in Prague who dispatched the medicine immediately. Blackett was not in London at that time and Kapitza's cable was passed on to John Cockcroft who got the medicine and sent it to Moscow by air without delay: on the parcel which was the first to arrive in Moscow there was only the following short inscription, 'For Landau'.

In 1969 Kapitza was asked to write an acticle about Landau for the collection *Biographical Memoirs of the Fellows of the Royal Society.* Kapitza provided a brilliant account of his closest collaborator; he had worked with Landau since 1937.

'His basic strength as a scientist', wrote Kapitza of Landau, 'lay in his clear and completely logical thinking founded on very wide erudition. But this strict attitude did not prevent him from recognizing the aesthetic side of science, which led him to use his feeling not only in his evaluation of scientific achievement but in the evaluation of the scientists themselves. Landau was always ready to give his appraisal which was apt and usually witty, especially in negative criticisms. These witticisms were quickly passed around and finally reached the subject under criticism, which naturally complicated Landau's relationships with people, especially when the subject of his criticism occupied a responsible position in academic circles.'

Landau was the founder of a large school of Soviet theoretical physicists who now occupy an honoured place in world science.

I think they loved each other and felt a close spiritual kinship. Both of them embarked on their path firmly convinced that a new era of science in the life of our planet was inevitable.

These two outstanding men had entirely absorbed into their consciousness the multifaceted culture of their time, in which physics figures so prominently but not at the expense of other fields of knowledge and art which even helped them to solve many scientific problems. Physics itself, perhaps, appeared to Kapitza and Landau to be a great art possessing a bewitching force of influence on mankind.

ON ANOTHER FRONT
(the Great Patriotic War, 1941-1945)

And on another front
You crush the enemy...

A. Tvardovsky

June 1941. The radio announced that the Nazis had invaded the Soviet Union. Many of the country's major industrial areas were in danger. The government made a decision that many plants and factories, scientific institutions and higher educational establishments must be urgently evacuated eastward. Physics research, mathematics and certain other institutes in Moscow and Leningrad, included in the network of the USSR Academy of Sciences, were evacuated to Kazan, the capital of the Tatar Autonomous Soviet Socialist Republic.

In 1928, together with other guests Max Born (famous theoretical physicist and professor of Göttingen University) visited Kazan, the venue of the Sixth Congress of the Russian Association of Physicists. This is how he described the city: 'The visit to Kazan was the highlight of the Congress. The old Tatar city, now the capital of the Tatar Soviet Republic, is located on picturesque hills some seven kilometres from the Volga: in the past, at the time Kazan was conquered by the Russians (1552), it flowed past the walls of the city but has retreated since then due to the rotation of the Earth. The city contains old architectural monuments built at the time of the Tatars and impressive Russian structures–churches and palaces.'

During the war Kazan provided shelter to many scientific institutions. After two weeks of preparation for evacuation, during which the entire staff of the Institute of Physical Problems worked hard to pack up valuable equipment and apparatus, the day of departure arrived. Trains left the Kazansky station in Moscow with their lights turned off.

There were neither signals nor schedules. The adjacent Komsomolskaya Square was cluttered with cases and piled high with bundles. People sat and lay on them. When an air-raid alert was given all would rush to get under shelter and the deserted square, filled with their belongings, looked even more eerie.

Upon arrival the staff and instruments of the Institute of Physical Problems and of the Lebedev Physics Institute were housed in Kazan University. Later the Leningrad Physico-Technical Institute also arrived in Kazan.

The Moscow premises of the Institute of Physical Problems on Vorobyovskoye Shosse were occupied by the headquarters and political department of the 5th Moscow infantry division. To commemorate the stay of the military units there a marble plaque has been set up on the facade of the Institute's main building. The Kapitzas, and Pyotr Leonidovich's staff-member Elevter Andronikashvili (who was soon joined by his brother, the well-known man of letters Irakli Andronnikov) for the moment remained at the Institute. Professor Arkadi Migdal (now an Academician) also stayed there. At the end of October 1941 Kapitza invited Abram Alikhanov and his wife, recently evacuated from Leningrad, to his institute and they put up in Landau's vacant flat.

Staying on in Moscow Kapitza displayed uncommon energy. In their *Pravda* article 'An outstanding Soviet physicist' published on 10 July 1944 Pisarzhevsky and Fedorov wrote: 'We remember Kapitza flew in a cold, freight-carrying Douglas to Kuibyshev in the company of boxes full of parts for tanks after he had dispatched to Kazan the last train-loads of equipment of the evacuated Institute of Physical Problems... Calm and methodical investigations had to be skipped over several stages at once. From Kuibyshev he rushed to Moscow which was bristling with snow-covered anti-tank hedgehogs and cubes. He worked harder than ever before, without refusing to make any speeches or provide any consultations, casting aside all thoughts and cares except this one: to use all his knowledge and experience, there and then, to immediately strengthen the defence effort.'

On 12 October 1941 the Hall of Columns of the Central Trade Union House was the venue of an antifascist rally chaired by Academician N.S. Derzhavin. 'Comrade

scientists,' the chairman began to speak with emotion, 'the cruelest enemy of the freedom and independence of nations, the deadly enemy of the Soviet Union, that sadist and murderer of nations, that bestial brute, bloody Hitler with his demoralized murderous hordes has insolently invaded the territory of our sacred Motherland.'

'When our country was suddenly attacked by Hitlerite gangs at the end of June', said Kapitza addressing the rally, 'all our scientists made the immediate decision that they must devote all their knowledge and strength to assist their country in its heroic struggle against Nazism.' Kapitza described the contemporary condition of the exact sciences and technology in Germany, which, he believed, had sharply decreased because many first-class scientists of 'non-Aryan origin'–Franck, Stern and Karman–had been banished from their country. In conclusion Kapitza urged scientists to join the struggle 'for freedom and culture, a struggle of which the world has never seen the equal, passivity in which shall bring indelible disgrace on any person.'

Later, the famous radio announcer Yuri Levitan read Pyotr Leonidovich's speech over the radio. In the most critical days of the war it sounded as a patriotic call addressed to the entire Soviet people.

When Kapitza came to Kazan the equipment of the institute had already been placed in the university building formerly occupied by botanists and zoologists and assembly work was under way amidst cases filled with skeletons and stuffed birds and animals. The staff lived in the hall and gymnasium of the University whose space was divided with the help of sheets into family and single compartments. Kapitza with his wife, children and father-in-law Academician A.N. Krylov, who was 78 in 1941, settled in the house where the famous Russian mathematician N.I. Lobachevsky, rector of Kazan University, had lived in the early 19th century.

The Leningrad Physico-Technical Institute occupied the premises of the ethnographic museum of Kazan University. Several laboratories separated from each other by plywood partitions hardly reaching the ceiling were squeezed into the large hall of the museum. The corner partitioned off by cases was Ya.I. Frenkel's study. Next to him the 29-year old experimental physicist G.N. Flerov was engaged in assembling measuring apparatus. He was getting ready to

resume the investigations of neutrons interrupted by the war.

Academician Tamm has told how the workers of the Physico-Technical Institute used some of the exhibits of the ethnographic museum for their own purposes: one of the scientific researchers ground a handful of rye that he had obtained with great difficulty by means of primitive millstones that had belonged to some Indian tribe. Food problems distracted the staff from scientific work; much time had to be spent on the tilling of tiny kitchen gardens, and searching for food, as well as on exchange and sales of belongings.

From the very start of its life in Kazan the Institute of Physical Problems began assembling the equipment to produce liquid air and gaseous oxygen. Soon afterwards the Institute began to supply oxygen to Kazan hospitals to cure the wounded and sick. Liquid air was also sent to munition factories. 'The national demand for oxygen increases in wartime,' Kapitza said. 'Every effort must be made to construct industrial-type machines and solve the problem of durability and service life. This we did in Kazan where the Institute was relocated after the wartime evacuation. At the same time the urgent construction of large-scale industrial plants began, and these are being brought into production on the basis of the Kazan experience, using our drawings and with the cooperation and guidance of our institute.'

During the war P.L. Kapitza built the world's most powerful turbine installation to produce large quantities of liquid oxygen Soviet industry needed. It was a difficult task to put the new method of producing liquid oxygen into practical operation and build the powerful turbine installations designed by Kapitza, particularly in wartime. A separate Oxygen Board called Glavkislorod was set up under the Council of Ministers of the USSR. Its main tasks were to develop and apply Kapitza's plants for the production of liquid oxygen. Kapitza was placed in charge of this organization. For the first time in his life Kapitza headed a governmental institution combining this post, which was unusual for him, with that of director of the Institute. Pyotr Leonidovich stressed that the aim of the Oxygen Board was 'to create a tie between science and industry, to use oxygen for the intensification of our metallurgy, chemical industry, power industry, etc.'

In 1942 Kapitza, Ioffe and Vernadsky were urgently

summoned to Moscow to participate in an important governmental meeting. At the meeting the question was raised of the appointment of a scientific director of work on the 'uranium problem'. Ioffe did not hesitate to propose the candidature of I. V. Kurchatov, his disciple and collaborator. Kapitza did not himself take part in the work on solving the 'uranium problem', which was so brilliantly organized and supervised by Kurchatov. Despite this some foreign authors without the slightest grounds have proclaimed Kapitza 'father of the Soviet atom bomb'.

In the summer of 1971 Kapitza received two books from abroad. These were the English and Italian translations of his booklets published in Moscow under the titles *A Life for Science* and *Theory, Experiment, and Practice*. The book published in London and entitled *Peter Kapitza on Life and Science* has an introduction written by its translator Albert Parry. He writes: 'In the early 1940s Kapitza returned to the atomic field by helping other Soviet scientists in their nuclear researches. He built new instruments for the cosmic-ray observations which were installed in the high mountains of the Pamirs and Soviet Armenia by the two Armenian brothers, Abram and Artemy Alikhanov. During the war Kapitza experimented with uranium and lectured on atomic physics in Moscow's military academies.'

During the war Abram Alikhanov was indeed invited to Erevan by the Academy of Sciences of the Armenian SSR. With a group of physicists he investigated cosmic rays on the Aragats mountain. In 1944 Kapitza did help Alikhanov to build a big permanent magnet for the magnetic spectrograph used by the Aragats station. But that was all. The other data cited by Parry are not true.

Abram Alikhanov, just like Pyotr Kapitza, was Ioffe's pupil; before the war he worked for some years at the Leningrad Physico-Technical Institute. Kapitza met Alikhanov in Moscow in the summer of 1943 after the Institute of Physical Problems had returned from evacuation. Alikhanov had been summoned to Moscow together with Kurchatov to organize work on the 'uranium problem'. It was then that he told Kapitza he was investigating cosmic rays in the Aragats mountain. Realizing that Alikhanov's researches were of great value for science, Pyotr Leonidovich suggested that Alikhanov should make his preparations for

the expeditions to the Aragats at the Institute of Physical Problems. Alikhanov willingly accepted Kapitza's offer. He believed that, in spite of the fact that he was busy organizing the laboratory which was supposed to conduct scientific and design work on the 'uranium problem' (now the Kurchatov Atomic Energy Institute of the USSR Academy of Sciences), he would, as before, be able to participate in the high-mountain expeditions.

The data obtained during an expedition to the Aragats mountain in 1943 were processed with Landau's participation. Collaboration with the outstanding theoretical physicist strengthened Alikhanov's intention to go on with his investigations of cosmic rays working from the Institute of Physical Problems. In the autumn of 1944 Alikhanov's expedition group was taken on the Institute's staff. Kapitza secured the allocation of considerable sums for the expedition group. Alikhanov was now able to start the design of specific apparatus for the expedition, including the above magnetic spectrograph.

When constructing the ionization chamber there re-emerged the method suggested a long time ago by the young Kapitza for drawing out quartz fibres by using a bow and arrow. Suddenly it was discovered that they had run out of quartz fibres brought from Leningrad, and without them it was impossible to adjust the electrometer. Shalnikov, who was very keen on making all sorts of 'delicate objects', was asked to help. He took a properly made arbalest from a laboratory cabinet and checked whether it was all right.

Quartz fibres for an electrometer must be thinner than a human hair. Such thin fibres can be seen with the naked eye only against a black background in reflected light. Once Kapitza had used black velvet for this purpose. Shalnikov said he had had such velvet put by, but it had disappeared during the evacuation. He tried substituting the black paper used in photography for velvet, but the fibres could not be seen on it. Shalnikov recalled that Alikhanov boasted not long before that by chance he had bought a dress length of black velvet for his wife's concert recitals (Alikhanov's wife, Slava Solomonovna Roshal, was a violinist). They began discussing how that velvet could be coaxed out of Alikhanov's wife. Shalnikov was authorized to hold the 'difficult negotiations' with her.

It is easy to understand what a precious possession velvet

was in those hard times for an artist giving recitals. Shalnikov was eloquent in seeking to prove that the velvet was absolutely essential for the physicists; if they failed to get it, he argued, expeditions to the Aragats would have to be cancelled. Naturally Slava Solomonovna gave back the velvet, for she did not wish 'to retard progress of science'. The velvet was put on the floor of the magnet hall and quartz fibres sufficient to last for another 15 years were drawn with the help of the arbalest. To the great joy of the 'victim' Shalnikov solemnly returned the velvet which was still quite wearable.

In April 1944 *Pravda*, *Izvestia* and other papers printed under big headlines a TASS report that the Franklin Institute in Philadelphia had awarded Academician Kapitza the Franklin Medal for his outstanding contribution to experimental and theoretical physics, 'especially in the field of magnetism and low temperatures'. The same report announced that Academician Ioffe had been elected a member of the British Physical Society.

The Franklin Institute was founded in 1824. The Franklin Medal was introduced in 1915 and in the past had been awarded to Edison, Einstein, Planck, Rutherford and Thomson. Kapitza was the first Russian scientist to ever win the award. The presentation ceremony was held at the All-Union Society of Cultural Relations with Foreign Countries (VOKS) on 23 May 1944.

During the Second World War the USSR, Britain and the USA were allies in the struggle against Hitlerism. Contacts among scientists and scientific institutions of the allied countries expanded. These contacts were not only of scientific but also of political significance. The Medal was awarded in the presence of many Soviet scientists and public figures, at a ceremony attended by the US Ambassador in the Soviet Union and the Embassy staff. Present in the hall were Vice-President of the USSR Academy of Sciences Ioffe, Academician Krylov who had already been awarded the title of Hero of Socialist Labour, and Academicians N.N. Semenov, A.N. Frumkin and V.S. Kulebakin.

In his speech the Chairman of VOKS said that the award of the Franklin Medal to the Soviet Academician was a further step aimed at consolidating the cultural and scientific ties between the peoples of the USSR and the USA. These

Kapitza in the Institute of Physical Problems, 1945

ties had assumed special significance during the war. The American press was right to point out, the speaker stressed, that the Red Army had saved world civilization from the barbarity of Hitlerism. And to the victories of the Red Army, he went on, Soviet scientists had made a great contribution which was highly valued in the allied countries. During the war there was an increasing reciprocal interest of American and Soviet scientists in the achievements of science in both countries. The Chairman of VOKS reminded the audience that the prominent American physicist Professor Ernest Lawrence had been elected an honorary member of the Academy of Sciences of the USSR.

Then it was Kapitza's turn to speak.

'A month ago in Philadelphia', he said, 'our ambassador in the United States, Comrade Gromyko, was kind enough to receive this award at my request from the Presidium of the Franklin Society. I asked him to express to the audience my feelings and sincere gratitude for the great honour paid to me by the award of the Franklin Medal and election as an honorary member of this, the oldest and foremost scientific society of the United States...

As I see it, this award is a manifestation of friendliness towards Soviet science by the American scientific community, as well as a recognition of its contribution to world science and of the efforts it is making to promote our common cause. In the historic days of joint struggle...for survival, for freedom and culture, in this sacred struggle in which the greatest strain and attendant hardships fell to the lot of my own country, any manifestation of sincere friendship is accorded an invariably warm welcome in our country.

We, scientists, are above all partiots and servants of our homeland, but at the same time we feel a special pride when the fruits of our work can influence the development of world culture... But these days are days of struggle, and we are faced with new tasks. Our science is called upon to stand up to the insanity of the Nazi ideology and its destructive manifestations. We know that the crippling and distorted use of science and its achievements could have led human culture to a catastrophe, had it not been for the joint and concerted efforts of our United Nations.

In this struggle of the united forces of progress scientists today bear a double responsibility. War in itself is an old historical calamity. But its present far-reaching forms are

largely due to the technology developed on the basis of phenomena discovered by scientists in laboratories, such as electricity, radio waves, various chemical reactions, and so on. While scientists sought to help man and promote his cultural growth the same achievements in the hands of the exponents of the criminal Nazi ideology have been turned against people...'

Kapitza's last remark reminds one of the famous words of Pierre Curie when he received the 1903 Nobel Prize. Foreseeing the possible use of radioactivity for military purposes Curie said: 'One can assume that in criminal hands radium might be very dangerous, and in this connection one may ask: Will mankind gain by perceiving the secrets of nature? Is mankind mature enough to benefit from them, or will this knowledge do mankind harm? In this respect the case of Nobel's invention is very typical: powerful explosives have made it possible to carry out remarkable work. But the same explosives turn out to be a terrible weapon of destruction in the hands of criminal rulers who plunge nations into wars. I belong to those who think, like Nobel, that for mankind new discoveries will be a source of benefit rather than evil.' Kapitza, like other progressive-minded scientists, for instance, Frédéric Joliot-Curie, thought that first of all scientists themselves must combat the forces that use scientific discoveries to bring about evil.

Concluding his speech Pyotr Leonidovich said:

'We, scientists, must do all in our power to overcome the forces of evil and strike from their hands the results of our labour which they have so grossly misused. This is our most immediate task... But in promoting the defence of our countries we must also raise our voices to ensure that the peace that will set in after the war rests on a firm foundation, that a healthy ideology prevails in it, that its economic system rests on a scientific basis, and that mankind is at long last delivered from a recurrence of the calamities it has suffered during the past years...

On the medal which I have the honour and pleasure to receive the image of Benjamin Franklin, a great champion of freedom and democracy and servant of his nation, is coined. About 200 years have passed since he lived and worked. Over the years a great deal has changed in the way we live, in our state organization, in our science and in our relationships. But the great ideas of humanism which

Franklin served have remained unshakable for us. For us he continues to be an example of a bearer of the great ideas of democracy and freedom... Therefore, I regard this medal on which the image of the great scientist and democrat is engraved as a symbol of the further uniting of the efforts of Soviet and American scientists both in wartime and in the period of forthcoming reconstruction.'

Kapitza ended his speech by saying that he was 'confident that all my fellow-scientists in this country share my feelings and aspirations for our common victory, and together with me experience profound satisfaction at the evidence of the friendliness of the scientists of the United States, which served as an occasion for our meeting today.'

Later Kapitza participated in the Pugwash movement uniting scientists from many countries in the struggle against the use of scientific achievements for military purposes.

In 1943 the Institute of Physical Problems returned to Moscow. The staff started installing the equipment and putting the premises in order. Once again, work was in full swing in the buildings on Vorobyovskoe Shosse. Things soon returned to normal and the Institute continued its investigations. At the same time it had to carry on work on defence projects – the war was still being fought.

The time the Institute spent in Kazan was not wasted. During wartime evacuation despite great difficulties Kapitza and his staff managed to build very efficient liquefiers for industrial and military purposes. The government appreciated these efforts. A few days before the end of the war the newspapers carried a Decree of the Presidium of the Supreme Soviet of the USSR (dated 30 April 1945) that P. L. Kapitza had been awarded the title of Hero of Socialist Labour.

The text of the Decree read: 'In recognition of his successful scientific development of a new turbine method of producing oxygen and of the creation of a powerful turbine-oxygen plant for the production of liquid oxygen the title of Hero of Socialist Labour has been conferred on Academician Pyotr Leonidovich Kapitza, and he has further been awarded the Order of Lenin and the "Hammer and Sickle" Gold Star'.

MAY TIME WORK FOR US!

(Moscow 1945-1967)

The centuries are delivered from their burden,
They bring fruits with year, and day, and hour.
So while we still have a moment of time,
May it work for us!

S. Marshak

By this time Kapitza's services to science had more than once been commended by the government of the Soviet Union: he had twice been awarded the State Prize (First Degree in 1941, Second Degree in 1943) and on three previous occasions he had received the Order of Lenin. (He would again be awarded the Order of Lenin in 1964 and 1971.)

And suddenly a sharp turn of fate. People appeared who did not approve of the research conducted by the Institute and they made their views public. After a time a commission was set up to find defects in the work of the Institute and defects were found. The turbo-expansion method was cancelled: piston refrigerator machines were declared to be more efficient. Fault was found with the Institute's style of work.

Pyotr Leonidovich had to leave the Institute.

Pyotr Leonidovich told me that when he stayed at his dacha almost uninterruptedly he was sent Stalin's work *Economic Problems of Socialism in the USSR* for review. Kapitza wrote a very critical 17-page review incidentally reproaching Stalin for mixing up or rather confusing the laws of the development of society with those of nature. However, Stalin did not take offence and his relations with Kapitza continued to be good. According to Kapitza Stalin could listen to criticism and even agree with it. But at the same time you never knew quite what to expect of him. Stalin could act in a most unexpected way.

In 1950 the administration of the Academy of Sciences offered Pyotr Leonidovich a job at the Institute of Crystallography of the USSR Academy of Sciences; the Institute was headed by Alexei Shubnikov, one of A. F. Ioffe's

outstanding disciples, a long-time researcher at the Leningrad Physico-Technical Institute, then a Corresponding Member of the USSR Academy of Sciences (later Academician), and one of the most prominent Soviet crystallographers.

Of interest is the short autobiography Pyotr Leonidovich submitted to the personnel department of the Institute:

'I was born in Kronstadt on 9 July 1894. Son of an army civil engineer who worked on the defenses of Kronstadt. Father died in 1921. Mother is engaged in literary and pedagogical work dealing with folklore.

In 1905 I entered the Kronstadt gymnasium which I had to leave in 1906 for poor progress. In the same year I was transferred to the technical school which I finished in 1912. Then I received electrical-engineering training at the Petrograd Polytechnical Institute. After completing my studies in 1918 I defended my graduation paper in physics and stayed on there as a lecturer in physics and mechanics.

Between 1918 and 1921 I carried out scientific work in the Department of Physics at the Polytechnical Institute.

In 1921 I went on a mission abroad together with Academicians Krylov and Ioffe to purchase equipment.

In 1921 I was admitted to the Cavendish Laboratory as a researcher where I worked from 1921 till 1934. In 1923 I defended my thesis on "Passage of α-rays through matter and methods of producing strong magnetic fields" and was awarded a doctorate by Cambridge University.

In 1923 I received the James Clerk Maxwell Prize.

In 1929 I was elected a Fellow of the Royal Society of London, and later in the same year a Corresponding Member of the USSR Academy of Sciences.

In 1924 I became Assistant Director of the Cavendish Laboratory and in 1930 was made a Professor of the Royal Society and Director of the Royal Society's Mond Laboratory at Cambridge University.

1934, winner of the Medal of the University of Liége.

Since 1935 Director of the Institute of Physical Problems of the USSR Academy of Sciences.'

During his work at the Institute of Crystallography which lasted from 1 June 1950 till 15 November 1953 Kapitza advised staff members on their investigations and delivered a few scientific lectures, including some dealing with his research into the theory of pendulum oscillations.

P. L. Kapitza, 1945

Between 1946 and 1953 the Institute of Physical Problems was headed by Academician Anatoli Petrovich Alexandrov, well-known for his research into nuclear physics and atomic power. (In 1976 Alexandrov was elected President of the USSR Academy of Sciences; before that he had for many

years been in charge of the Kurchatov Institute of Atomic Energy of which he is still director.) Having replaced Kapitza for a considerable time Alexandrov managed to preserve the scientific traditions of the Institute of Physical Problems and its other distinguishing features.

In the late 1940s Kapitza set up a small laboratory at his dacha. He made all the things he needed by himself–he was a metal turner, milling machine operator, joiner and electrician, all at the same time. Pyotr Leonidovich continued to work on the problem that interested him both theoretically and experimentally. He called this problem 'high power electronics'. Kapitza's definition seemed paradoxical at first sight, for electronics is a field dealing with low power, and that is its distinguishing feature. But after the publication of a number of articles on this problem and of the fundamental work 'High-power electronics' Kapitza's research in this field attracted the attention of scientists at home and abroad. A domestic laboratory, however, convenient though it was, could hardly be used for low temperature investigations.

One part of the investigations conducted in the laboratory on Nikolina Hill was devoted to the study of the ball lightning phenomenon. As early as 1940 *Zhurnal eksperementalnoi i teoreticheskoi fiziki* (Journal of Experimental and Theoretical Physics) of which Kapitza was Editor-in-Chief) had carried Frenkel's article 'On the nature of ball lightning'. Fifteen years later, in 1955, *Doklady Akademii Nauk SSSR* published Kapitza's article under the same title. There is no evidence that Kapitza's interest in ball lightning had been prompted by Frenkel's work. It is interesting to note that the mystery of this rare natural phenomenon had attracted the attention of two prominent physicists–a theorist and an experimenter. Naturally, Kapitza had read Frenkel's article and when they met they may have discussed problems relating to ball lightning.

In his childhood and youth Kapitza often heard stories about ball lightning. In ancient times and during the Middle Ages ball lightning was regarded as retribution sent to people for their sins. Those who witnessed ball lightning described the terrible devastation it caused. And at present, though electrical phenomena occurring in the atmosphere have been investigated fairly thoroughly, interest in ball lightning has

not slackened. Attempts continue to establish an authenticated theory of this phenomenon.

According to Frenkel, ball lightning is a globular vortex in a mixture of dust or smoke particles with chemically active gases whose activity is caused by an electric discharge. The globular vortex is on the whole electrically neutral and can independently exist for a long time. Frenkel developed an electromagnetic model of ball lightning. Later it was further developed in a new discipline – magnetohydrodynamics which studies motion of completely ionized plasma.

Frenkel explained the ability of soaring ball lightning to avoid obstacles by the effect observed when vortex rings are in motion and conditioned by the laws of aerohydrodynamics. To explain the explosion of ball lightning Yakov Frenkel used Semenov's theory of chain chemical reactions for which Semenov was awarded the Nobel Prize in chemistry. Frenkel considered it natural that there exist upper and lower concentration limits of different substances at which they either react or cease to react with each other. In Frenkel's view, a chemical reaction occurring as a chain process at a tremendous rate is, in fact, an explosion.

Kapitza believes that Frenkel's theory and all the other hitherto advanced theories of ball lightning have one essential drawback – they contradict the fundamental law of nature, the law of energy conservation. 'It was hard to imagine', Pyotr Leonidovich said, 'that prominent scientists could have ignored the law they learned when still at school! It was easier to conceive that there are natural phenomena so difficult to account for that they compel a researcher to resort to the most subtle tricks in order to explain them. If you follow Frenkel's idea you must agree that ball lightning has a great amount of internal energy.' But according to Kapitza's calculations the internal energy of this kind of lightning is quite insufficient to cause the observed effect.

Kapitza offered a new explanation of the nature of ball lightning. Basing his arguments on the law of energy conservation he maintains that energy is continuously being supplied during the luminiscence of ball lightning. The sources of this energy are outside the boundaries of ball lightning, not within the ball lightning itself as Frenkel believed. It may be the energy of ultrahigh frequency

radiation in the metric and decimetric wave bands occurring, along with other electromagnetic waves, during atmospheric discharge. UHF radiation is intensely absorbed by ball lightning which is a kind of resonator. Ball lightning develops as a powerful oscillatory process in the electric field of a cloud, or near the earth surface. The fact that ball lightning is a rather rare phenomenon shows that far from every atmospheric discharge is accompanied by the oscillatory processes that cause ball lightning.

In Kapitza's opinion, significant evidence for the correctness of the radio wave theory of ball lightning is its characteristic motion in the atmosphere, and its ability to penetrate into buildings through chimneys, slits and sometimes along wires, or to suddenly emerge from telegraph or telephone sets. There have been even cases of ball lightning appearing in the hermetically sealed compartments of jet airliners. Ball lightning fairly accurately follows the features of a terrain at a certain altitude. This can also be explained by the motion along the antinodes of reflected radio waves of the same intensity and length. Ball lightning bursts when the energy supply is suddenly cut off, e.g. in case of a sharp change of the wavelength, the sphere of rarefied air collapsing in the process.

Kapitza advanced the theory of the radio wave nature of ball lightning after he had conducted experiments in the field which he called high-power electronics. For these experiments he used the Nigotron (the Nigotron was so named after Nikolina Gora, Nikolina Hill) – a powerful source of microwave oscillations. Experiments with the Nigotron confirmed the feasibility of concentrating a large amount of electromagnetic energy in small volumes and of transferring it over considerable distances without any significant losses. By using the Nigotron Kapitza obtained electromagnetic radiation of up to 8 kW in a decimetre range of the electromagnetic wave spectrum.

According to Pyotr Leonidovich, in his first experiments he let the radiation out of the window. Then he decided to try and see how this radiation affects different objects. 'At first', he said, 'we placed an egg in the path of radiation, which immediately boiled hard, and Academician Fok, who happened to be there, ate it up at once.' For the second experiment Kapitza took a quartz ball 10 cm in diameter, filled with helium at a pressure of 10 cm Hg. According to

calculations at the available strengths of the electric field a "breakthrough" was to occur. Indeed, there was a flash, a bright flash in a very small area inside the quartz ball. 'No sooner had I admired it', said Pyotr Leonidovich, 'than the ball melted, although it was a quartz one, and it was all over. I watched it for only a few seconds. This phenomenon made such a strong impression on me that a year or two later I decided to associate it with ball lightning.'

After the first experiments with the Nigotron had been completed Kapitza decided to use it for investigation into thermonuclear processes. He started his plasma experiments in which a thin plasma filament was confined at the maximum of the electric field. Kapitza considered such confinement to be more reliable than the one attained by means of a magnetic field.

He maintained that the application of ultra-high frequency electronics in the field of high-power engineering is 'one of the most promising trends in the development of modern electrical engineering'. By concentrating large amounts of electromagnetic energy in small volumes it is possible to convert high frequency energy into the kinds necessary to accelerate elementary particles or to heat and confine plasma.

In Kapitza's opinion, an important application of high power electronics is to transmit electric energy via waveguides inside underground tubes rather than along wires. Transmission of electric energy through waveguides will make the construction of bulky and expensive high-voltage lines unnecessary, and the question of insulating high-voltage lines will no longer arise.

How does such transmission occur? Direct current is converted into a high-frequency one by means of a magnetron and is then pumped into the waveguide. At the end of the waveguide another magnetron converts the high-frequency current back into the direct current used for power needs. High-frequency current can also be used directly, for example, by feeding it to a blast furnace. This will raise the temperature in the blast furnace. High-frequency current may also prove useful to heat the ground around boreholes when prospecting for, and extracting, oil.

Perhaps, high-power electronics will make it possible to transmit electromagnetic energy through space as a directed beam without waveguides, just like radio waves (such

methods of energy transfer have been described in science fiction novels). If this were feasible, it would be possible to provide a continuous supply of electric energy to satellites and space stations without overloading them with complicated hardware needed for self-sustained operation.

Developing the idea of high-power electronics Kapitza was well aware of the fact that electronic processes had not yet been investigated thoroughly enough, that a great deal was yet to be done in this respect and that only then could the alluring prospects, which are difficult to foresee, open up.

In his dacha on Nikolina Hill Kapitza worked hard to tackle some of the topical problems of mathematics and mechanics. In his reports to the Presidium of the Academy of Sciences in those years he mentioned, among other things, the theoretical research he had carried out only with 'paper and pencil'. Here are some of the investigations Pyotr Leonidovich completed in 1951:

'1. Evaluation of the sum of negative even powers of roots of Bessel functions.

2. Dynamic stability of a pendulum when its point of suspension vibrates.

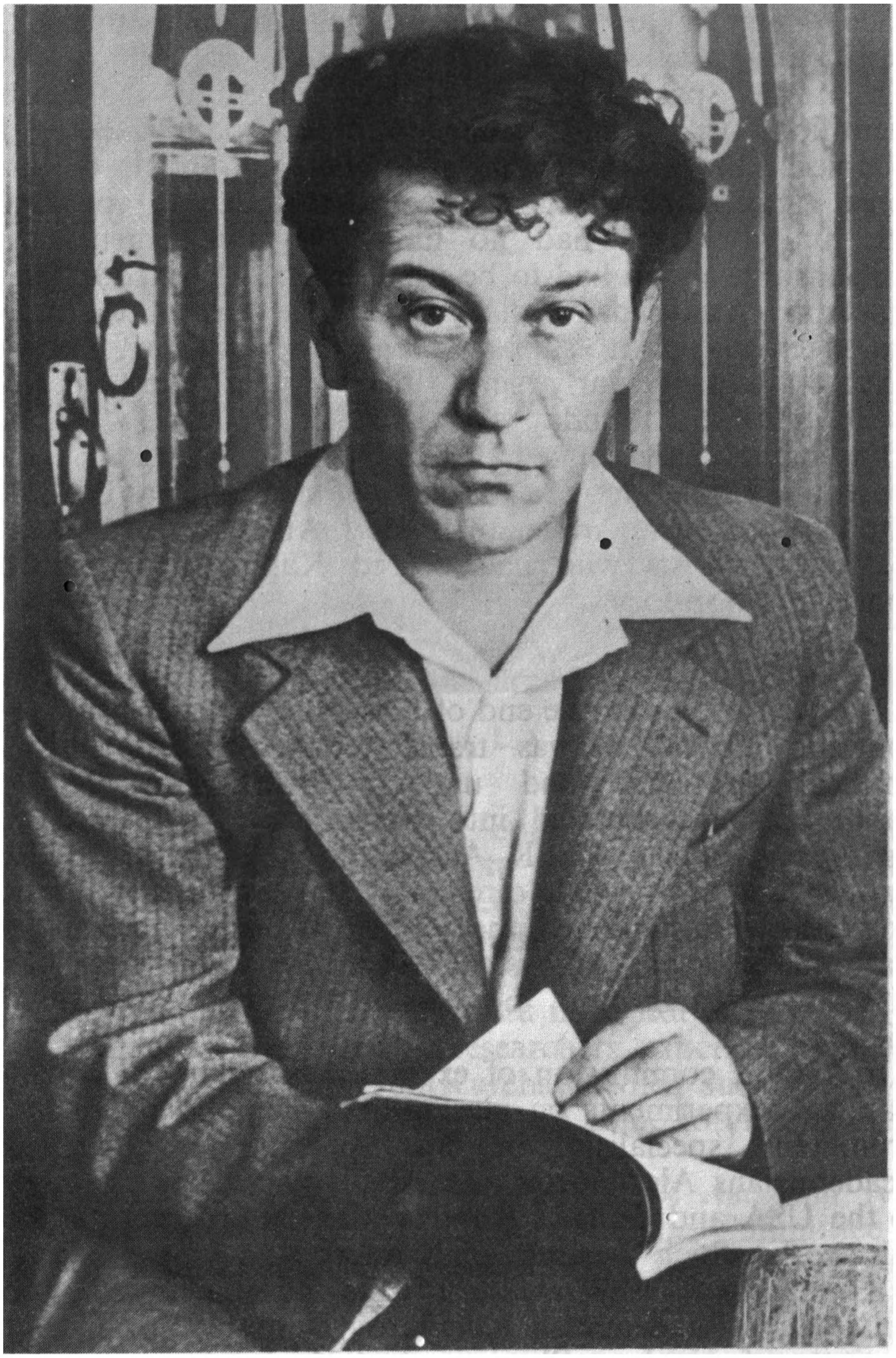
3. Pendulum with a vibrating suspension.

4. Heat conductivity and diffusion in a liquid medium under periodic flow conditions. Determination of the wave transfer coefficient in a tube, gap and channel.'

Being unable to dwell on these scientific papers regarded by specialists as most original and interesting, let me just say that Kapitza can with good reason be called not only an outstanding experimental physicist and engineer but also a brilliant theoretical physicist.

Basing himself on the account given by Kapitza's closest collaborator, S. I. Filimonov, D. Sc. (Physics and Mathematics), the writer E. Dobrovolsky has described the atmosphere in which the investigations were conducted.

'The caretaker's hut', Dobrovolsky writes, 'was turned into a hut-laboratory. It was nicknamed IFP–*Izba Fizicheskikh Problem* (the hut of physical problems). The hut consisted of two rooms, a kitchen and a garage. The machine shop was equipped with a lathe, a miller, a drill, and a tool-grinding machine. Near the laboratory there was a small shed turned into a joinery shop. The hut's stove had only recently been replaced by hot-water heating... There was not enough



Academician Abram Alikhanov, 1947

space, therefore an extension was added and called "the hold".

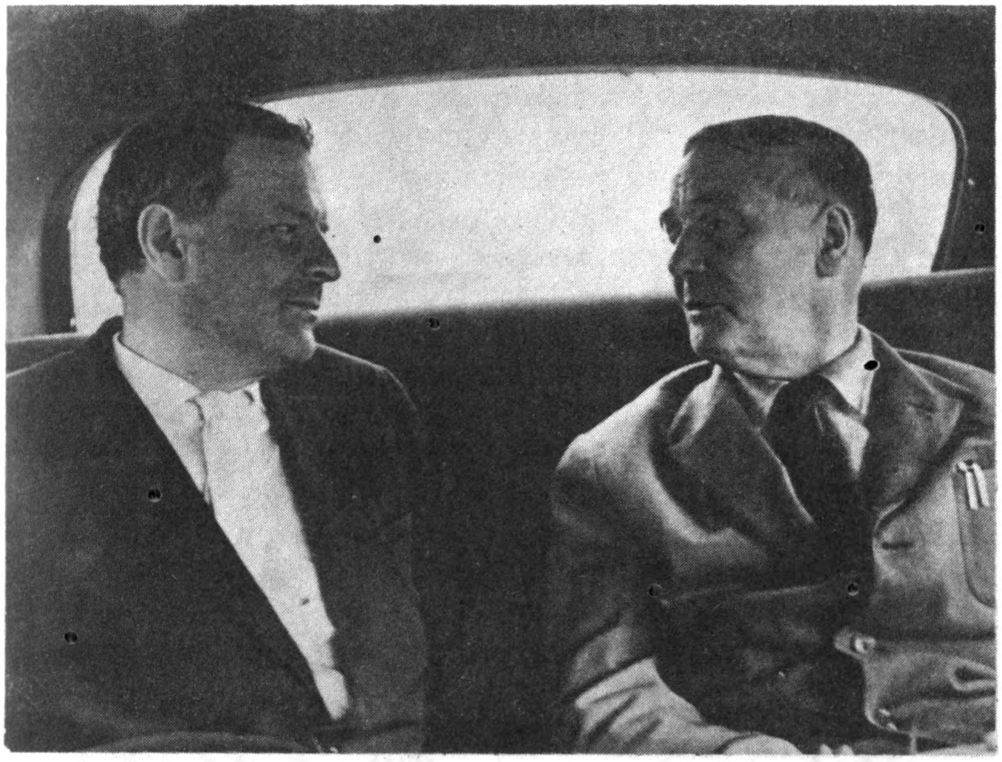
As time passed packing-cases appeared containing scientific journals and books. Another room had to be occupied. The laboratory began to encroach on the dwelling house. Once some silver was needed to make an apparatus. The hut-laboratory had no funds for noble metals and a silver table-spoon had to be used instead. At exactly ten to two Anna Alexeevna would invite those present to dinner, and at ten to eight, to supper. Then they would watch TV or see a film, particularly since there was a film-projector.'

Almost every Sunday Academician Abram Alikhanov would come to Nikolina Hill to see the Kapitzas. As a rule he would bring along a basket of fruit and a bottle of Kapitza's favourite Armenian brandy. Alikhanov was one of the few scientists who had helped Kapitza to equip his domestic laboratory.

The year 1954 saw the end of Kapitza's long seclusion. His domestic laboratory was transferred to the Institute of Physical Problems and under the title of 'Physical Laboratory' was entered into the official list of scientific institutions of the USSR Academy of Sciences. In 1955 Kapitza was again made director of the Institute of Physical Problems. He combined the job of Institute director with that of director of the Physical Laboratory where he went on with his research into the plasma filament, launched on Nikolina Hill.

In 1967 a commission of experts was set up to consider Kapitza's experiments on plasma. The commission included prominent specialists in hot plasma, in particular, Academicians Alexandrov and Artsimovich. During his trip to the USA and Canada Kapitza made a few reports about this work, which aroused great interest.

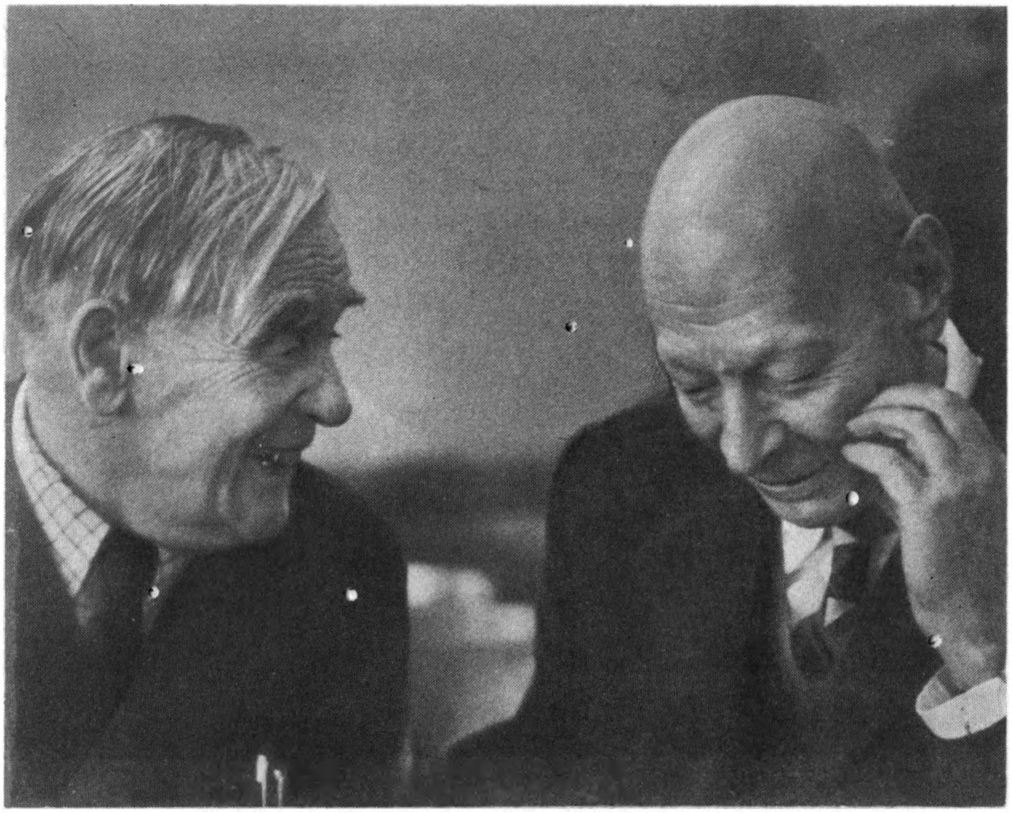
Kapitza was well aware of the plasma investigations initiated by Academician Kurchatov in the 1950s. Then the Institute of Nuclear Physics which had been engaged in research on the atomic problem built the large Ogra installation to study thermonuclear fusion. Early in February 1960 Kurchatov invited Kapitza to his office and acquainted him with the achievements attained in thermonuclear research in which Artsimovich had played the leading part.



Kapitza with Academician L. A. Artsimovich, 1965

Perhaps Kurchatov, who could organize and unite scientists into large collectives to provide a joint 'industrial' solution of extremely complicated tasks in physics – tasks that require a concerted effort by theorists, experimenters and designers, wanted to draw Kapitza into investigations on thermonuclear fusion. But Kapitza must not have responded to the request to join the researchers experimenting with Ogra. On 7 February 1960 Kurchatov died suddenly in the park of the sanatorium where he had come to visit his friend Academician Khariton.

In December 1970 the journal *Vestnik Akademii Nauk SSSR* carried a paragraph stating that the Committee for Inventions and Discoveries of the USSR Council of Ministers had registered Kapitza's discovery: 'The formation of high-temperature plasma in a filamentary high-frequency discharge at high pressure'. The same year saw the publication of Kapitza's article entitled 'A thermonuclear reactor with a plasma filament freely floating in a high frequency field'. The article included a drawing of the construction of a thermonuclear reactor operating according to the principle suggested by Pyotr Leonidovich.



Kapitza talks with A. P. Alexandrov, the President of the USSR Academy of Sciences, 1977

Kapitza could well support the words of Academician Artsimovich printed in *Literaturnaya Gazeta* on 17 September 1971: 'I hope that in the next century the problem I am working on – the generation of thermonuclear energy – will be resolved. It is now hard to foresee how it is going to happen and what path will lead us there.'

In Kapitza's experiments a thin plasma filament floated in the middle of a resonator in an atmosphere of deuterium at a pressure of several atmospheres. Spectroscopic measurements and theoretical calculations led Kapitza to believe that in this case there appeared a cylindrical region of a radius of several millimetres filled with hot plasma possessing very high electron-and-ion temperature. The difficulties facing an experimenter are that he must accurately measure the temperature of the plasma filament and determine whether the neutrons observed in the experiments are of a thermonuclear origin or not, in other words, whether the process of thermonuclear fusion of hydrogen nuclei takes place.

What does Kapitza's method of plasma confinement in a high-frequency electric field briefly consist in?

A constant high frequency power is supplied into a metal chamber filled with gas at high pressure, whose size depends on the wavelength of electromagnetic oscillations (one of Kapitza's resonators was one metre long and 10 cm in diameter). Along the axis of the chamber-resonator, where the electric field is at the maximum, there develops a plasma filamentary discharge. The end of the filament reaching into the region of a weaker electric field dies out, whereas the temperature of the filament located in the region of a stronger field increases. The filament is thus confined in the region of the strongest h.f. field. But the plasma filament formed in the resonator suffers radial instability, i.e. it tends to drift away from the axis to the chamber walls (this process is called floating up). Floating up of the discharge is prevented by rotating the gas that surrounds the filament. Centripetal force draws the filament to the axis.

Kapitza's article on investigations of the filament concludes thus: 'The production and study of the thermonuclear process in the filament can, of course, have a great practical significance for nuclear energy; but in addition to that, a study of the filamentary discharge itself, in which hot plasma exists continuously at exceptionally high temperatures and high pressures, must lead to a deeper scientific understanding of a number of plasma processes.'

Pyotr Leonidovich is deeply convinced that thermonuclear fusion will play an important role in power engineering. His research in this field is continuing.

HAIL THE PATH!

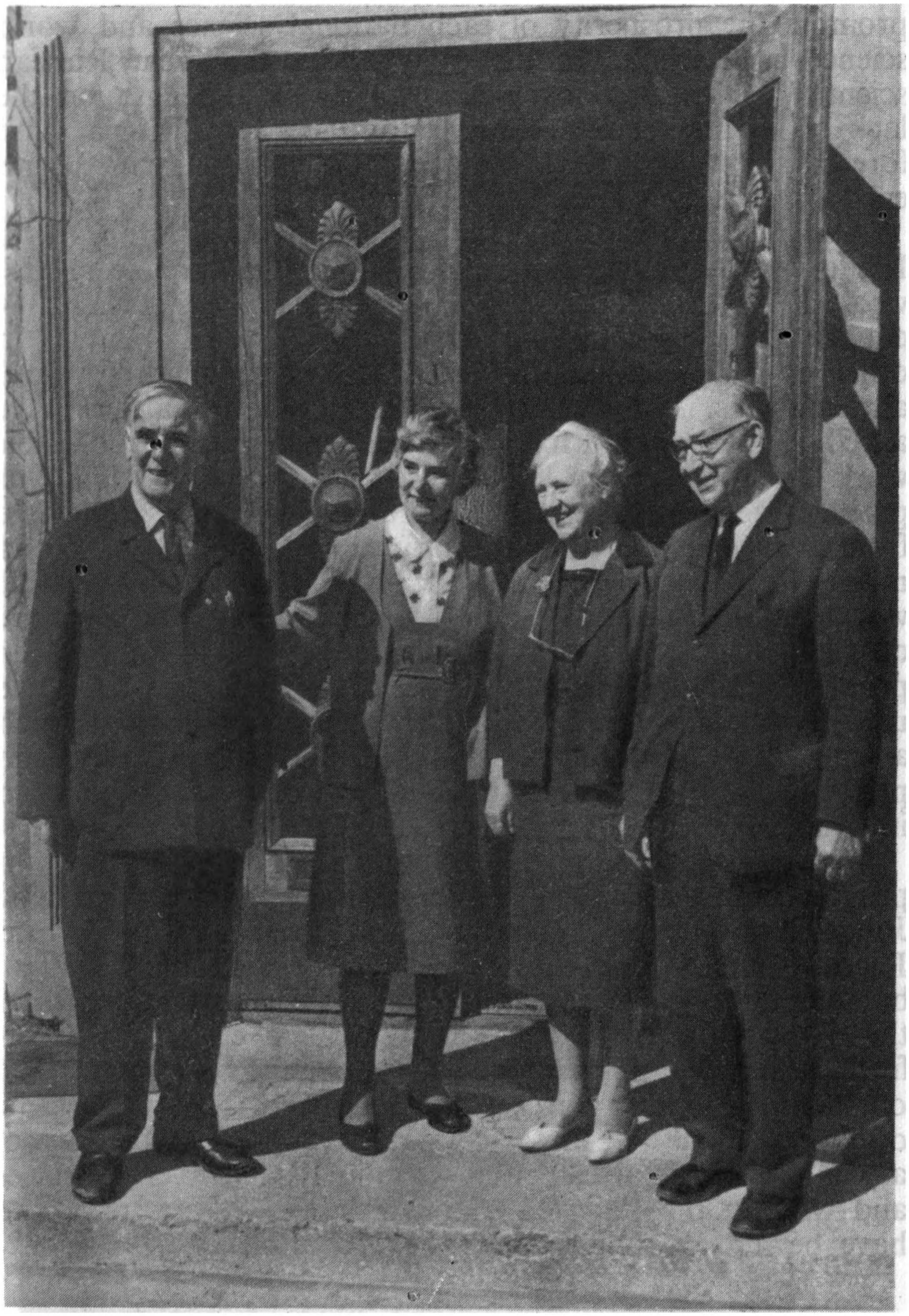
Hail the time!
Hail the path!
Be reckless:
Run the risk, don't be shy.

P. Antokolsky

In January 1965 the Danish Engineering Union awarded Kapitza the International Niels Bohr Medal. Pyotr Leonidovich was pleased to learn the news but he did not feel like going to Copenhagen. 'It's cold over there,' he told me. But the climate in Copenhagen is not rigorous at all and the only thing that occurred to me then was to remind him of the warm Gulf Stream current washing the coasts of Denmark. Kapitza remarked melancholically that if he did go there it was necessary to give the King of Denmark a month's notice, as he was to present the Niels Bohr Medal in person. Besides, Kapitza would have to attend to a multitude of small matters, including his own wardrobe, and he had lost the habit of doing that.

For over 30 years Kapitza had not been abroad, even though there had been many invitations. Progressive-minded scientists of the West remembered the young Russian experimenter, Rutherford's talented disciple and friend. In all countries there were students of Rutherford who had met Kapitza at Cambridge or at international scientific conferences in England, France, Belgium, Holland and Germany – while living in Cambridge Kapitza visited so many countries! Now his Cambridge friends, just like he himself, had turned from young, ebullient people, who were quick off the mark, into elderly celebrated professors, encumbered with numerous honorary duties, titles and awards. Some of them had won the Nobel Prize and many became heads of departments at universities in Europe, the USA, Canada and Australia.

Kapitza has always considered international meetings of scientists to be extremely important and necessary to



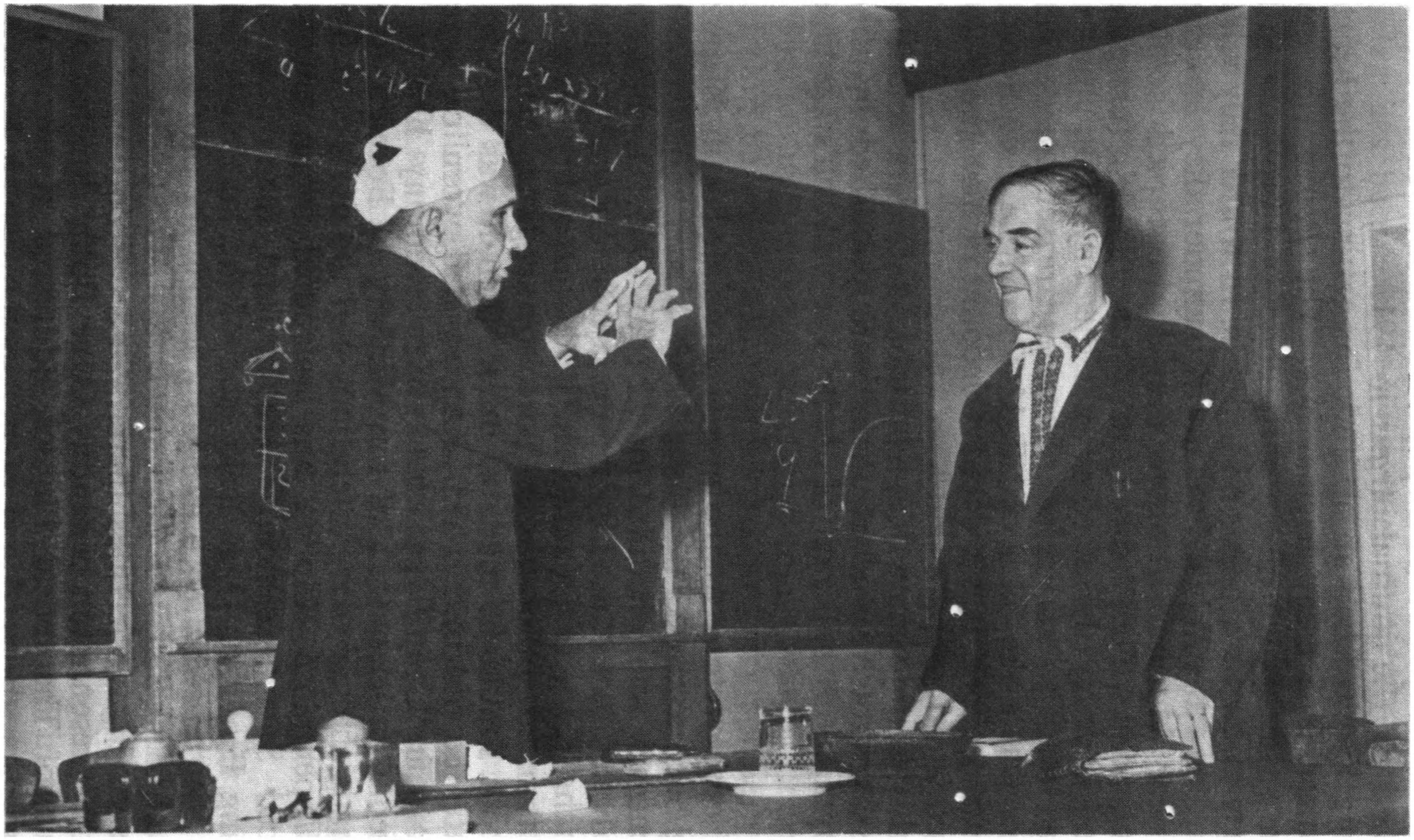
P. L. Kapitza and J. Cockcroft with their wives at the Institute of Physical Problems, 1965

promote the prosperity of each national science and world science as a whole. In his essay about the great Russian scientist M. V. Lomonosov Kapitza dwelt at length on the lack of contacts in the 18th century between Russian and foreign scientists, which hampered their acquaintance with each other's achievements.

'The tragedy of isolation from world science of the work of Lomonosov, Petrov, and others of our solitary scientists', wrote Pyotr Leonidovich, 'consisted only in the fact that they could not be included in the collective work of scientists in other countries, since they had no opportunity to travel abroad. This is the answer to the question that we have asked, that of the reason for the lack of influence of their work on world science... Since each scientific field or problem can develop only in one direction lest it deviate from its true course, it is necessary to move slowly and spend much effort in exploratory work. Collaboration in scientific work means that these laborious exploratory studies are distributed among groups of scientists working on a given problem. The work done by a scientist outside the collective usually remains unnoticed. Experience shows that such a collective effort of scientists can occur only through personal contact, either within a country or on an international scale.'

In this respect, Kapitza was in complete agreement with progressive-minded Communist-scientists such as Frédéric Joliot-Curie or Paul Langevin. The Chairman of the World Peace Council Joliot-Curie said that of all the fields of human endeavour science provides the brightest examples of the tremendous advantages the world can enjoy if there is free movement of people and exchange of ideas. The outstanding French physicist maintained that any scientific discovery made in any one place was a completion of a whole series of investigations conducted in different places and without the knowledge of which that discovery would have been impossible.

Ever since he was a child Kapitza has been fond of travelling. When he travelled he would carefully observe life and make many discoveries for himself, and not only scientific ones. When Pyotr Kapitza was only 19 he went on vacation to the White Sea coast in the North. Already then



Kapitza with the Indian physicist Raman during a seminar at the Institute of Physical Problems, 1958

All of us who had the opportunity to listen to his lecture received a strong impression of his ability, even in a very complex field of physics and engineering, to penetrate to the core of the matter and to see the simple fundamental relationships. It was also inspiring to witness the imagination and scope of his thoughts and to hear him tell about his recent achievements in a new domain of research, and talk about his vision of the developments to come in twenty, thirty, forty years hence.

Peter Kapitza is not only an outstanding scientist, but, as all those who have had the opportunity to meet him will have realized, also a truly great personality. His mind is alive to all the problems of life, which he is always able to see with fresh and independent eyes. This makes it exciting to be together with him and listen to his comments which so often open new perspectives. He does not shy away from a hot debate and may even enjoy taking unconventional viewpoints, but behind his words one always feels the detached mind ever searching for truth and never lacking the courage to speak it out.

This is an occasion to recall the close personal relations between my father and professor Kapitza which go back to the days of Cambridge and to the very close association which they both had with Lord Rutherford, that towering figure in the history of science. I know what admiration my father felt for Kapitza's scientific achievements, and how greatly he valued his friendship. He also felt that the deep devotion they both had to Rutherford was a close tie between them...

My parents had the pleasure of visiting Professor Kapitza and his family in Moscow, first in 1937 and later in 1961, just a few years ago. I can imagine few things that would have given my father greater pleasure than to be able to welcome Peter Kapitza at the occasion here.

Among the hopes attached to the award of the Niels Bohr Medal is that it will contribute to strengthen the contact between Danish scientific and technical circles and outstanding scientific endeavours in the various parts of the world. Through the years, many Danish scientists have had the opportunity to visit the distinguished Kapitza Institute in Moscow and have always carried away with them valuable and stimulating impressions. We hope that this connection will further develop in the years ahead.

We also greatly welcome that Professor Kapitza's coming to Copenhagen to receive the award has been taken as an occasion by the USSR Academy of Sciences to send a special delegation of scientists, headed by one of the very distinguished Soviet physicists Academician Konstantinov, as an important step towards the further extension of the cooperation between physicists of the Soviet Union and Denmark, which in recent years has developed so fruitfully. Professor Konstantinov is head of the Physico-Technical Institute in Leningrad which is another outstanding scientific institution of the Soviet Union. For many years the Institute for Theoretical Physics here in Copenhagen has had a valuable contact with the Physico-Technical Institute.'

In January 1966 Kapitza received a letter from the British Institute of Physics and the Physical Society signed by the President of the Society Sir Gordon Sutherland:

'Dear Academician Kapitza,

It gives me great pleasure to inform you that the Council of the Institute and Society has awarded you the 1966 Rutherford Medal and Prize in recognition of your many contributions to physics, including those on which you worked in Lord Rutherford's Laboratory. It consists of a bronze medal accompanied by a prize of fifty guineas.

All the Institute and Society's awards are presented on the occasion of our annual dinner and soirée in London and this will be held at the Savoy Hotel on Tuesday, 3 May. We should be delighted if you and your lady were our guests on that occasion. May I add that the recipients are not expected to reply after the brief citation has been read by the President and you have received your medal from me.'

The Rutherford Medal was especially dear to Kapitza. By the time of the award of the Medal Pyotr Leonidovich was already the holder of a large number of medals received from scientific institutions of many countries. Shortly before Sutherland's letter arrived Kapitza showed me his medals which he keeps in a safe in his study. On one of the gold medals I saw the image of Niels Bohr, and on many gold, silver and bronze medals there were inscriptions in different languages.

For the award of the Rutherford Medal Kapitza was to go to England which he had left so long ago. Of course, he remembered Cambridge very well. His English retained typical Cambridge words and expressions (this was noticed by journalists at Kapitza's press-conference in Cambridge).

Shortly before Kapitza the 'chess academician' Mikhail Botvinnik visited Cambridge. He found the house Pyotr Leonidovich had lived in and described it in his wonderful essay *In the Chess Albion*. Now in Free School Lane, not far from the Cavendish Laboratory, one could see an ultra-modern tall laboratory building of concrete, steel and glass, which had not existed before.

At the end of April 1966 Pyotr Leonidovich and his wife Anna Alexeevna came to England by plane. On the appointed day he took part in the ceremony in the Savoy Hotel during which Sir Sutherland handed him the Rutherford Medal to the applause of 400 guests.

The President of the London Royal Society Sir Patrick Maynard Blackett (an old friend of Kapitza's), who attended the ceremony, asked the guest to speak in London of his reminiscences about Rutherford. Addressing the Royal Society Kapitza told, in particular, how Rutherford who had at one time been the President of the Society, had taught him the art of reporting to its members: 'Show as few slides as possible,' he used to say. 'When the hall is dark, the listeners take advantage of this and leave.' Kapitza strove to draw a live image of the great physicist in his speech. Stressing Rutherford's enormous contribution to world science Kapitza said that his teacher had not pondered over questions dealing with the organisation of collective scientific work. He might have regarded an all-out attack on a given problem to be of little use or absolutely meaningless. But it was precisely in this way, contrary to Rutherford's approach, that modern experimental physics had been developing.

On his return to Moscow Pyotr Leonidovich gave a talk about his trip to England at a seminar of the Institute of Physical Problems and showed his photographs to those present. The light was turned off and on the screen there appeared the picture of the Rutherford Medal followed by photographs of Kapitza and Cockcroft during the banquet at the Savoy Hotel. When the two aged gentlemen in dress-coats appeared on the screen a hesitant voice was heard in the hall:

'And there should also be a cap!'

'No, there should be no cap,' replied Pyotr Leonidovich. 'It is a dress-coat and not a professor's gown. A cap must go with a gown. And now I will tell you a story about the gown.'

Thus the unusual story of the doctor's gown was entered into the minutes of the Institute's seminar. Such insertions are typical of Pyotr Leonidovich's reports and speeches. Their purpose is to let his listeners relax psychologically, giving them a short rest so that they can perceive serious subjects with a more active appreciation.

So, Kapitza told the audience that on one occasion he dined in Trinity College in the company of Lord Adrian, an old colleague of his, and other scientists. In the college everything was the same as 30 years before. Familiar pictures were hanging on the walls. And still Kapitza felt a little awkward. Suddenly it dawned on him that all the people around were wearing gowns and only he had no gown on. He remembered that he had once left his doctor's gown hanging on the hook in the entrance passage of Trinity College. Having beckoned to the butler Pyotr Leonidovich said to him: 'I left my doctor's gown in the passage. Would you see if it's there, please?' The butler asked politely: 'When did you leave it in the passage, sir?' Kapitza replied: 'Thirty-three years ago.' The butler showed no surprise: 'Yes, sir, of course, I'll have a look.'

'Just imagine', Kapitza burst out laughing, 'he did find my gown.'

'That very gown?' someone asked.

'You're being unnecessarily demanding,' Pyotr Leonidovich replied. 'The gown was a perfect fit and looked like mine.'

Kapitza's son Sergei Petrovich intervened:

'The fact that the gown was a perfect fit proves that it was the wrong one.'

'Nobody there doubted that it was my gown,' Pyotr Leonidovich responded. 'In England I was never asked such questions.'

Actually, there was one person in England who had doubts about it. At one of the banquets Pyotr Leonidovich was approached by a government minister who asked confidentially: 'Could you please say if the gown story is true or not?' Kapitza replied to the untrusting minister: 'The only thing I invented is that I did not specify when I received the gown. And I received it not the same evening but the next morning. This was the only liberty I took in narrating the gown story.' The minister remarked that this deviation could be pardoned. But the gown story did not end there. According to Kapitza, at a diplomatic reception in Moscow

displaying a practical outlook, Kapitza paid attention to the oil which the local Pomors obtained from cod liver. This trip resulted in Kapitza's first paper – an essay 'Cod-liver Oil' published by the journal *Argus* in 1913.

Young Kapitza had an aptitude for getting to the heart of the matter. The essay begins thus: 'The *Pomors* are good Russian seafarers who from early childhood are used to the sea; they know its caprices and secrets. In winter they inhabit the shores of the White Sea, but in summer they leave and settle near Murmansk where they are occupied solely in catching cod. They dwell in '*stanovishche*' (temporary dwellings) along the shores and the bays. On the site, amongst the filth and refuse, factories are set up, i.e. small factories where the oil is clarified.' The whole essay took up five journal pages. It is a detailed account of how the *Pomors* catch cod and prepare cod-liver oil.

On his first journey Kapitza took a camera and made many snapshots. Some of them were published in *Argus*. (Photography is still one of Pyotr Leonidovich's pastimes.)

But let us return to the events associated with Kapitza's having been awarded the Niels Bohr Medal. The departure for Denmark was scheduled for 22 May 1965. The main fuss before he left was caused by the dress-coat. He was to appear before the King of Denmark in it; he needed a dress-coat rather than any other clothes. Someone suggested that a new dress-coat should be made to order; then it was decided to renovate the old one, which Kapitza had worn on several occasions in Cambridge when strict ceremony had to be observed. At the tailor's of the Ministry of Foreign Affairs they made the necessary alterations and the dress-coat fitted.

In Copenhagen Kapitza was welcomed as an envoy of advanced Soviet science. There he met many scientists, including Professor Ogge Bohr (son of the late Niels Bohr) whom Pyotr Leonidovich had known when the professor was still a child; he visited the famous Institute of Theoretical Physics and gave lectures there.

At the presentation ceremony Ogge Bohr, director of the Institute of Theoretical Physics, addressed Kapitza. What follows is an abridged text of his speech (which he gave in English):

'It is my privilege, on this festive occasion, to say a few words of tribute to our honoured guest. The outstanding contributions to science for which Pyotr Leonidovich Kapitza has been awarded the Niels Bohr Gold Medal by the Danish Engineering Society, have already been cited by the chairman in his welcome address. These are the achievements which in a very important manner have pushed forward the frontiers of physical science by opening new possibilities for experimental research, especially in the domains of very high magnetic fields, and very low temperatures. In these domains Academician Kapitza has also made great discoveries, among which, perhaps, the most well-known concern the peculiar properties of liquid helium, which, at very low temperatures, behaves as a macroscopic quantum system.

Kapitza's creative genius and his ability to inspire his co-workers have also found expression in the famous Institute for Physical Problems which he has organized in Moscow. In this Institute he has gathered around him a team of outstanding colleagues and pupils, which under his leadership has been able to play such a very special role in the exploration and analysis of the properties of condensed matter, and has earned the admiration of colleagues all over the world.

We see in Peter Kapitza a worthy representative of the great and long tradition of Russian science, and he stands as one of those who, exploiting the new opportunities for science in the Soviet Union, laid the foundation for the present brilliant achievements of Soviet scientists.

Kapitza's scientific work is characterized by his mastery of the art of experimentation, and by his deep insight in the technical aspects of experimental research. He was originally trained as an engineer, and is a great example of the new category of engineering physicists...

Kapitza, indeed, to a rare degree, is a master of both physical and engineering science... He has devoted great effort to making the connection between science and industry mutually fruitful. We know that also in this manner he has been able to render very important services to his country, the appreciation of which has found expression in the many awards and honours which have been bestowed upon him and his institute.

the British Ambassador approached him and asked about the gown. Kapitza was forced to tell the story again.

Sergei Petrovich Kapitza told me that the story of his father's gown has become part of Cambridge folklore. Sergei Petrovich visited England in July 1966, soon after his father. In Cambridge he told the story of his father's gown to the Director of the Mond Laboratory, Professor Shoenberg. Shoenberg made up his mind to check right away whether the story was true. Both of them went to Trinity College where Shoenberg wanted to test the reputation of College porters for remembering faces: he wondered if the Trinity porter would recognize Sergei who looked so like his father. In fact the porter did not recognize him, but when told his name, the porter said, 'Oh, yes, I remember whom you mean. It was the gentleman whose gown we had to find not long ago.' Sergei was much impressed by this direct evidence of truth in the 'folklore'.

In September 1966 on the invitation of the Boris Kidrič Institute of Nuclear Physics Pyotr Leonidovich visited the Socialist Federative Republic of Yugoslavia. It was largely a car trip and the chauffeur and Kapitza's son Andrei Petrovich took turns in the driver's seat. Kapitza met Professor Pavle Savič, Director of the Institute of Nuclear Physics, and the institute staff. In Belgrade Kapitza was received by Josip Broz-Tito. In 1967 at a festive ceremony in the Yugoslav Embassy in Moscow Pyotr Leonidovich was presented with the Order of the Yugoslav Banner with Ribbon, one of Yugoslavia's highest awards.

Kapitza liked Yugoslavia very much. Once he told me that the Adriatic Sea coast of Yugoslavia is much more picturesque than that of Italy. He also remarked that the car trip along Yugoslavia's excellent roads had saved plenty of his time.

On his way to Yugoslavia Kapitza visited Budapest where he was presented with the Hungarian translation of his book *Life Devoted to Science* which had just been published there. Back in Moscow Pyotr Leonidovich learned that his book had also been translated into Japanese and would soon appear in Tokyo.

In October 1967 Kapitza left for Warsaw to attend the International Scientific Symposium commemorating the birth

The degree ceremony at Charles University, Prague 1965

centenary of Marie Sklodowska-Curie. There were several academicians on the Soviet delegation and Sergei Petrovich Kapitza was also a member. For Pyotr Leonidovich Marie Curie was not only a symbol of the amazing achievements of the human mind in 20th century science: he remembered her as the charming lady to whom he had been introduced by Abram Ioffe when they both visited the famous Institute of Radium in Paris.

In 1968 the Netherlands Society of Refrigeration bestowed on Kapitza the Golden Kamerlingh Onnes Medal. In the 1920s Pyotr Leonidovich visited the Netherlands several times. (Kamerlingh Onnes, who was then past seventy, was still in charge of his famous laboratory). In Leyden Kapitza discussed his investigations with Ehrenfest who held the chair in theoretical physics at Leyden University, which had been vacated by the retiring Lorentz. Kapitza already met Ioffe's close friend Ehrenfest in Petrograd where the latter had lived for many years. Once, when Kapitza came to see Ehrenfest at White Roses Street in Leyden everyone was waiting for Einstein. On that occasion the Ehrenfests were preparing

a musical programme in which Einstein himself was also to take part. Ehrenfest would play the piano and Einstein, the violin. The ensemble had not always attained perfection and Ehrenfest said to Kapitza: 'Mind you, Einstein is no virtuose, but you'd better not try to find fault with his violin playing; criticize his work in physics – he is infinitely tolerant about that.' The concerts were held in Ehrenfest's study where there was a Hupfeld piano Einstein had presented to Ehrenfest and a violin for Einstein. Regrettably, that evening Einstein did not come.

At Ehrenfest's house one room was intended for guests. Ehrenfest asked anyone who came to see him to sign his name on the wall of the visitors' room. Over the years many wonderful scientists had left their autographs there. Here one could find signatures of physicists, such as Bohr, Planck, Born, Heisenberg, Pauli, Schrödinger, Fermi, Debye, Ioffe, Shalnikov and many others.

When Kapitza visited the Netherlands again to receive the Golden Kamerlingh Onnes Medal in Leyden, Paul Ehrenfest had long been dead. Pyotr Leonidovich met Ehrenfest's family and visited the house in White Roses Street, which was associated with dear recollections about his friends and the days of youth that would never return.

Leyden lagged behind modern giant cities and looked somewhat old-fashioned. But for Kapitza it for ever remained the town of outstanding works of art and remarkable scientific achievements. It was there that the great Rembrandt had created his masterpieces and that the Leyden jar had been invented, which for the first time furnished a method of condensing electricity. It was there that Kamerlingh Onnes had liquefied gases and Lorentz, the second Nobel Prize winner in physics after Roentgen, had developed his famous transformations which played an important part in Einstein's creation of the theory of relativity.

In September 1970, the seventy-six year old Kapitza together with other members of the delegation headed by the President of the USSR Academy of Sciences flew to Madrid to attend the 13th General Assembly of the International Council of Scientific Unions. In the same year Pyotr Leonidovich and Anna Alexeevna made a long trip in

Canada and the USA. According to the established practice Kapitza later made a report on his trip at a meeting of his seminar at the Institute of Physical Problems. The Institute's assembly-hall was overcrowded that morning.

Pyotr Leonidovich began by describing the *Alexander Pushkin*, the sea liner on which Anna Alexeevna and himself left for Montreal. He dwelt at length on the stabilization system of the ship and showed two slides: views of Newfoundland Island and Quebec. In Montreal Kapitza visited several scientific institutions. He showed particular interest in Professor Stevenson's work on obtaining strong magnetic fields. Stevenson used an aluminium coil as a solenoid (Kapitza used a copper one). The coil was cooled with liquid helium at 10 K under pressure. Thus Stevenson managed to produce magnetic fields of up to 300,000 oersteds. Long before, Kapitza had obtained magnetic fields of over 500,000 oersteds, but those were pulsed fields of short duration. Stevenson obtained magnetic fields of long duration, their intensity being very high.

Montreal is the city of Rutherford. It was here that his scientific career began. Pyotr Leonidovich visited the Rutherford museum at McGill University. It was with emotion that he looked at the apparatus designed by Rutherford, about which he had only heard from his teacher. It seemed only a short while back that they had talked at the Cavendish Laboratory–but Rutherford, his wife and his daughter are already gone and many other Cambridge physicists besides; like old Cambridge itself, they have already become a part of history. At the Montreal Physical Society Kapitza read his 'Reminiscences about Rutherford'.

Now the next slide was shown–a room in a hotel of the Canadian town of Edmonton, and a bunch of dazzling red flowers in a small vase on the table. A Canadian girl gave the flowers to Anna Alexeevna at the airport. Handing the flowers to Anna Alexeevna she uttered a greeting which made a strange impression on the Kapitzas. Anna Alexeevna said to her husband: 'Either I no longer understand English or here in Edmonton they use some dialect.' The next day the misunderstanding was cleared up, when the girl's mother asked Anna Alexeevna: 'How did you like my daughter's welcome address in Russian? It took her so long to prepare.'

A few slides with landscapes of the Rocky Mountains were also shown, the photographs having been taken from the

train windows. Anna Alexeevna tirelessly made snapshots of the wonderful views opening up before her. Then came pictures showing the Houses of Parliament in Ottawa, and the photograph of Kapitza and Professor Webster with whom Pyotr Leonidovich had once made magnetic measurements in Cambridge.

From Ottawa Kapitza set out for the atomic centre at Chalk-River, founded by his friend John Cockcroft. Pyotr Leonidovich told the audience how the problem of using atomic energy for peaceful purposes was being tackled there. At Chalk-River he was presented with an apple grown on the great-great-granddaughter of the apple-tree under which Isaac Newton had once sat. 'I presented that apple to Academician Tsitsin', Kapitza smiled; 'he promised to propagate it.'

From the atomic centre the Kapitzas returned to Ottawa and from there they went to Boston and Harvard in the United States. At Harvard Kapitza was met by his old acquaintances Viktor Weisskopf and Eugene Wigner and viewed with admiration the magnetic laboratory of Harvard University.

The next slide showed an elderly man measuring the circumference of Kapitza's head. The speaker explained: Columbia University in New York had decided to confer a doctor's degree on him and the University authorities were getting ready for the ceremony. A doctor's gown and cap had to be made. A tailor was sent along to take measurements. To Kapitza's great surprise the University asked him what he weighed. Kapitza wondered why a tailor making a doctor's gown needed to know the client's weight. This question has never been answered.

While in New York Kapitza visited the famous laboratory of the Bell Telephone Company, a gigantic enterprise with 770,000 employees. Pyotr Leonidovich showed interest in a model of a push-button telephone set.

In Washington Kapitza was attracted by the recently built monument to Taras Shevchenko. Its erection was paid for with money donated by Americans of Ukrainian origin. In Moscow in front of the Ukraina Hotel there is also a monument to Taras Shevchenko, and this prompted the US Senate to make the following inquiry: Who is that Mr. Shevchenko to whom monuments have been simultaneously erected in both capitals?

From Washington the Kapitzas proceeded to San Francisco. There Kapitza visited the well-known Stanford University where he saw the laboratories and a powerful 20,000,000 eV accelerator. At that very time San Francisco was the venue of the Columbus Procession which, according to Pyotr Leonidovich, is a very picturesque and interesting sight gathering thousands of spectators.

From San Francisco their itinerary took them to Pasadena. The slides showed abstract sculptures mounted in the university parks of Pasadena. At the university Kapitza met his old acquaintances Richard Feynman and Karl Anderson. He also held a discussion with students who listened with interest to the Soviet professor telling them about the achievements of science in his country.

Having told the students what they had not been aware of Kapitza playfully reproached them with ignorance. His listeners immediately demanded proof of this. 'All right,' said Kapitza, 'I'll prove it to you. Do you know the writer Washington Irving?' Several voices could be heard: 'Of course, we do.' 'But do you know that Washington Irving was ambassador to Spain and, using the rich archives provided by the Spanish government, he wrote his four-volume work *The Discovery of America* there?' It turned out that the students did not know that. Pyotr Leonidovich explained to them that Irving's work is considered to be among the best ever written on this subject. And how did Kapitza know about Washington Irving's four-volume work? In confidence he said that once, by chance, he had found this four-volume work in the library of his father-in-law Academician Krylov and read it. The audience broke into laughter. The Kapitzas returned to New York by car; on their way they crossed the Grand Canyon and visited Las Vegas. Having returned from the Pacific coast they put up at the hotel of the Rockefeller Institute. Shortly afterwards Columbia University held the solemn ceremony of conferring a doctor's degree on Kapitza. The students were barred from the ceremony, as there were fears of undesirable outrages. At that time student disturbances were sweeping America: Pyotr Leonidovich saw police at the university.

The next slide showed the St. George church in Wall-Street. Kapitza told how the well-known American multimillionaire Pierport Morgan would come there every morning. Once he was asked whether he was so religious

that he considered it his duty to visit the church in the morning. Morgan replied that the silence in the church helped him to calmly think over his affairs.

Kapitza's report was coming to an end. Pyotr Leonidovich dwelt at length on the methods used by American firms in selecting personnel and touched on the problem of crime in the United States. 'Now every American', said Kapitza, 'leaves home with a $100 bill with him. If he is attacked he offers this sum of money as a price for being spared. Such a large and wealthy country as America faces many difficult, almost insoluble problems.'

Kapitza finished his story and hurriedly descended the platform. He was surrounded by people and the talk continued. Although the report had lasted two hours Pyotr Leonidovich gave the impression that he was not tired at all.

In 1971-1972 Kapitza received many invitations from abroad: from Switzerland to come and give lectures there, from Professor Ogge Bohr to visit the Institute of Theoretical Physics in Copenhagen; from France to attend the Colloquium in commemoration of the birth centenary of Paul Langevin in Paris; and from Pavle Savič to visit Yugoslavia on the occasion of Kapitza's election as a member of the Yugoslav Academy of Sciences. In April 1972 Pyotr Leonidovich flew to Poland to receive an honorary doctor's degree at Wroclaw Technical University. A year later Kapitza paid another visit to England.

3 July 1973: a regular meeting of the seminar is being held in the assembly-hall of the Institute of Physical Problems. Kapitza is in the chair. After one of the reports is over he says: 'Four more reports are left. Which would you prefer: to listen to the reports or to an account of my trip to England?' There is general laughter which is correctly interpreted by Pyotr Leonidovich. He starts showing the slides at once.

The first slide shows Kapitza and David Shoenberg standing by the carved design of the famous crocodile marking the entrance to the Mond Laboratory. The next slides were taken inside the laboratory. 'In this very place there was a generator in the past', says Kapitza; he adds sadly: 'The Mond Laboratory is being moved out of town.'

A new slide. 'This is the house I lived in', Pyotr Leonidovich comments. 'There are 12 rooms in it. Now

twelve Soviet students on a studentship in Cambridge put up there. At one time my study was here. The poplars in front of the house were quite small when I left.'

In the slide you can see a girl but the image is indistinct. 'Can't you focus this lady?' Kapitza asks. Laughter in the hall. 'Here are the undergraduates of Cambridge', he goes on. 'These young Englishmen wear long hair and beards. Then everything comes back to normal. When they take a job they shave off their beards and get their hair cut, and wear decent clothes.' The next slide shows Churchill College in front of which there is a traffic jam. Kapitza says that after the Mond Laboratory this is the second modern building in Cambridge. 'There's a sculpture by Henry Moore,' he explains.

'From London Shoenberg and I went to Manchester to see Lovell's Observatory,' Pyotr Leonidovich narrates. 'Here he is, photographed in the company of four lords who came to see him. The lords are just as we imagine them – utterly silly. Lovell has to build two radiotelescopes but they will cost £11 million. That is why he has invited the lords to his place. Well, Lovell had a nice talk with the lords. He dazzled them with science. (Our Kurchatov was also keen on doing that. He always got the money he needed.) And this is Lovell's house and orchard. He is very fond of gardening and for hours on end works in the garden looking after his roses. The next slide shows the 14th century church in which Lewis Carroll was christened. And this is a stained-glass window on which scenes from *Alice in Wonderland* are shown.'

The last slides are devoted to London. Kapitza remarks that the British capital is becoming overgrown with sky-scrapers. Then he tells the audience how he happened to attend a symposium of physicists in Moscow, and a group of American physicists, on seeing him, suggested that they all should have their picture taken together. A man with a camera stepped out. It was the prominent American physicist Katz who had invented fine-grain film. Such film makes it possible to photograph from long distances. It was captured on the U-2 plane manned by US Air Force pilot Powers who had violated the state border of the USSR. Kapitza asked Katz bitingly: 'Is your film like the one used on the U-2?' 'No,' Katz answered in a nonchalant tone. 'This is a colour film.'

In January 1974 Kapitza left for India. He received an

invitation to visit the country as a guest of the Indian government. 'The purpose of the trip', Pyotr Leonidovich said, 'was to discuss the prospects of cultural exchange between our two countries.'

In February of the same year Kapitza went to Switzerland where the University of Lausanne conferred an honorary doctorate on him and some other foreign scholars. This was Kapitza's 32nd foreign honorary award. After the presentation ceremony Pyotr Leonidovich took a ten-day holiday in the Swiss Alps. On returning home he handed me via his secretary a copy of the speech he had delivered at Lausanne University. I cite it now in full:

'Mr. Chairman of the Senate, Mr. Rector, Messrs. Deans, My Dear Colleagues, Ladies and Gentlemen,

It is very difficult for me to express my gratitude for the honour which Lausanne University has done to me and my colleagues.

My eloquence is not sufficient to convey my sincere feelings on this festive occasion. I have no doubt that these feelings are shared by my colleagues here: Colin Martin, well-known for his works on numismatics; M. Jacques Burdet, the brilliant promoter of musical culture; Mr. André Martin, known for his works in the most modern field of nuclear physics; and Mr. David Shoenberg with whom I began to work at the Mond Laboratory in Cambridge 40 years ago and whose successes in low-temperature physics I admire.

I should like to add some more words to explain the reason for my emotion on this occasion. Let me remind the audience that early in the 18th century Swiss scientists were the first to be invited by the Russian Academy of Sciences which had just been established. These were the great Euler and the outstanding brothers Bernoulli. After his studies in Basel the 20-year old Euler was invited to Russia by Empress Catherine I to be a member of the Petersburg Academy. It was there that he began creating his famous works in mathematics and general mechanics, which are still classics. These investigations served as a foundation for the development of exact sciences in Russia. Bernoulli's works have provided basic ideas for the formation of the kinetic theory. It is interesting to note that Euler's 800 works will soon appear in 80 volumes: the publication of these works is

a joint venture of the Swiss and Soviet academies. The work has not yet been completed. At present such international cooperation is of special importance, as we face a number of unresolved global problems – those of energy, environmental pollution, and depletion of natural resources. It is on the solution of these problems that the future of mankind depends.

I should also like to point out that the honour done by Lausanne University to Swiss, French, British, and Russian scientists is evidence of international cooperation which is so important in science. This is another reason why this honour is so dear to me and why I experience a feeling of profound gratitude to Lausanne University.'

HUMANITY

But whether that fire will flare up or not
To you–heirs and brothers!–for all eternity
The people entrust their priceless gift:
Humanity redeemed from death.

O. Berggolts

Of late Pyotr Leonidovich has been paying great attention to ecological problems. At times Rutherford and his colleagues at the Cavendish touched upon these problems at 'five o'clock tea' or over a glass of port. But then they seemed to be very remote. Today mankind is faced with the real danger of extinction because of its irrational attitude towards nature.

Kapitza began his address at a meeting of scientists in the editorial office of the journal *Voprosy filosofii* (Problems of Philosophy) in November 1972 by saying that man's attitude to nature is a world-wide problem, and, hence, of special urgency. At present the global problems of man's life on Earth are assuming paramount importance.

'In our century', said Pyotr Leonidovich, 'the solution of many problems is beyond the powers of any single country and can only be achieved on a global scale. This realization of the planetary character of relations between man and nature emerged for the first time in the wake of the Atomic bomb and the threat of a global nuclear war. It is generally accepted that the outbreak of such a war in any part of the world could poison the entire globe and put an end to human life within a few hours. In view of this threat, mankind must renounce the use of nuclear weapons.

Some people still believe that man can survive a radioactive disaster by finding refuge in a shelter equipped with suitable filters. But this is a mere illusion, because man can only live in a balanced relationship with nature. And such a balance is unthinkable when a live man is surrounded by an environment devastated by the radioactive contamination after a global atomic war. Once out of his shelter, man would be doomed to die of protein starvation in

a world where all large animals have perished and natural equilibrium no longer exists.'

In Kapitza's view there are three major aspects of the global problems: a technical and economic aspect, linked with the depletion of global natural resources; an ecological aspect, namely the biological equilibrium between man and living nature, and a socio-political aspect. Kapitza believes that the dynamics of the processes linked with these global problems may be described by exponential function: eventually the process turns into an explosion.

Kapitza is of the opinion that 'mankind can solve its gravest energy problem by the use of controlled thermonuclear processes. The energy source for these processses is deuterium, a heavy isotope of hydrogen found in the oceans in practically unlimited quantities.' (It may be recalled that earlier Kapitza had underrated the 'possibilities' of the technical application of nuclear energy for the needs of mankind.)

As to the ecological problem, Kapitza thinks it is of lesser gravity than the depletion of raw materials but it is more acutely felt by people. According to Kapitza 'ecology must become one of the central biological sciences today. Its main task is not only to study the biological equilibria now existing in nature but, more importantly, to determine viable equilibria in a nature exploited by modern industrial processes, as well as the equilibrium processes associated with the extensive use of various chemicals in agriculture.'

According to Kapitza, a third aspect of the global problems is the creation of social conditions that would permit the application of technical and industrial achievements on a scientific basis that would ensure the balanced progress of civilization without the risk of an explosive catastrophe.

'I am convinced that the need to solve global problems on an international scale will encourage the efforts towards peaceful coexistence and disarmament... People will feel themselves as neighbours facing a common enemy – the impending global crisis which makes them join forces for a common struggle.'

Kapitza's field of interests is very broad. Being a great scientist he has a special bent for the history of science and

for the activity of its outstanding representatives. His essays about Rutherford, Langevin, Lomonosov, Franklin, Pavlov and other scientists are well known and loved by many readers.

Here is an excerpt from his reminiscences about Rutherford:

'Rutherford was very sociable and loved to talk to visiting scientists, of whom there were many. His attitude to other people's work was kind and considerate. In conversation Rutherford was very lively; he was fond of jokes and would often make them himself. He laughed easily, his laughter was sincere, loud and infectious. His face was very expressive: you could see at once what mood he was in, or whether he was worried by anything. You always knew he was in a good temper when he good-naturedly teased the person he was talking to. The more he teased the friendlier he was with that person. This was particularly noticeable when he talked to Bohr or to Langevin to both of whom he was especially attached.

His kindest jokes often concealed a deeper sense. I remember one occasion when he brought Professor Millikan to my room in the laboratory, and said to me: "Allow me to introduce you to Millikan. I am sure you know who he is. Show him the installation you use to obtain strong magnetic fields and tell him about your experiments, but I doubt if he will listen to you, as he himself will tell you about his own experiments." This was followed by Rutherford's laughter in which Millikan joined with rather less enthusiasm. Then Rutherford left us and I soon found out that his prediction was correct.'

In 1965 Znanie Publishers brought out a small collection of Kapitza's essays entitled *Zhizn dlya Nauki* (Life Devoted to Science). A review published in the *Novyi Mir* journal (No. 8, 1965) under the title "Meet Lomonosov, Franklin, Rutherford and Langevin" praised the book's conciseness of exposition, its original treatment of the activity of historical personalities, and the skill with which it drew a comprehensive portrait in an essay of a limited size. 'Within a small space', wrote its author Tendryakov, a well-known Soviet writer, 'great deeds are shown, remarkable characters are described and real discoveries recorded about those whom we thought we already knew.'

The reviewer paid special attention to the first essay

devoted to Lomonosov. The image conveyed of Lomonosov was devoid of unnecessary academic, 'bronze' solemnity. 'For all of us', wrote Tendryakov about the great Russian scholar, 'his name and image are firmly linked with bronze monuments. And those who gaze at you from high pedestals can hardly be fancied as living beings, and their life is still more difficult to analyze. But in this essay Lomonosov is not an ostentatious figure: the majestic tragedy of a genius is unexpectedly revealed before the reader. Peter I "hacked open the window" to Europe. But this "window" did not prove wide enough to let cultured Europe see through it the scholar who had grown out of the Russian soil and was capable of enriching world science with his great discoveries. Europe failed to notice Lomonosov. And so did Russia which was just being drawn into European culture.'

Pyotr Leonidovich received and continues to receive many letters from readers. He is always punctual in answering them. But there are also exceptions. In 1965 I showed him a letter addressed to him but received by the publishing house at which I then worked. The correspondent was a Candidate of Science who asked Kapitza whether his statement on the possibility of converting mass into an equivalent amount of energy might lead to the revival of the Ostwald energetics, a variety of idealist thought.

Kapitza listened to me attentively and then said: 'I will not answer his letter. It is a letter about religion rather than science. Many experiments have proved beyond doubt that in some processes, for example, in a chain reaction in uranium and similar elements, an enormous amount of energy is released, accompanied by a loss in mass. Today attempts to assert that mass does not convert into energy are similar to attempts to reject the theory of relativity or quantum mechanics. In the past the idea that it is impossible to convert mass into energy was stubbornly imposed not by means of scientific data but by charms and spells, which is tantamount to the assertions of various religious dogmas. And religion has really taken deep root in people. Such letters just like suggestions to build a *perpetuum mobile* should be left unanswered.'

There was no irritation felt in Pyotr Leonidovich's words. He spoke calmly being convinced that he was right.

On 6 February 1962 Kapitza gave an address to the General Meeting of the USSR Academy of Sciences. He dealt

with the criticism in the past years of the statement, stemming from the theory of relativity, that energy is equivalent to mass.

'Most criticism [on the part of philosophers] was centered on the conclusion that energy is equivalent to mass multiplied by the speed of light squared ($E = mc^2$),' said Pyotr Leonidovich. 'The philosophers thought that matter cannot disappear, and therefore this conclusion was false and idealistic. Physicists have already subjected this law of Einstein to tests with elementary particles. To understand these tests required a profound knowledge of modern physics, which some philosophers did not have. And by now the physicists have produced nuclear reactions and verified Einstein's law, not on individual atoms, but on the scale of the atom bomb, which became a reality.'

In his *Recollections of Lord Rutherford* Kapitza told of a small episode which happened in 1930 in the Cavendish Laboratory. At that time a conference was being held in Cambridge to commemorate the centenary of the birth of Maxwell, the first director of the Cavendish. 'After the official part of the meeting during which some of Maxwell's pupils talked of their reminiscences, Rutherford asked me how I liked the speeches,' writes Pyotr Leonidovich. 'I answered that they were very interesting, but I was surprised that all the speakers spoke only of the positive side of Maxwell's work and personality and made a "sugary extract" of him, and I said that I would like to see Maxwell presented as a living figure with all his human traits and faults, which, of course, every man possesses however great his genius.'

These words could well be applied to Kapitza himself. In 1939 in a talk to the staff of the *Detskaya Literatura* (Children's Literature) magazine Pyotr Leonidovich said of atomic energy: 'It is of great importance only in phenomena occurring in enormous masses. It certainly plays the decisive part in sidereal cosmogonic processes, but in the life of man – in the microcosmos, it probably does not play and will not play the role of an energy source. The sun and the stars maintain their radiation by this nuclear energy. Of course, one cannot be quite sure but there is every objective reason to assert that nuclear energy will not be used in earth's conditions. Rutherford also thought so.'

This statement of Kapitza has already been mentioned. To the ensuing question, 'So, you mean to say that

investigations in this field are of purely theoretical interest?' Kapitza gave the following answer: 'Under certain conditions we have learned to release intranuclear energy, but to bring about such a reaction a still larger amount of energy has to be expended.' This phrase needs some comment.

Two years before this talk took place Niels Bohr visited Moscow. Kapitza and Bohr were glad to see each other – they had not met for several years. In his lecture delivered at Moscow University in the presence of many physicists, including Kapitza, the Danish theorist said that energy dissipation, typical of all nuclear processes, prevents the realization of chain nuclear reactions. According to Bohr the entering of the very first particle into the nucleus is accompanied by energy dissipation, which even depreciates to some extent the energy spent to capture the particle by the nucleus. 'This circumstance', Bohr concluded, 'leads to somewhat gloomy prospects concerning one of the fundamental issues of atomic physics – the problem of using the atomic energy contained within the atomic nucleus.'

The delusion of many outstanding scientists as to the possibility of practical application of nuclear energy is one of the most surprising facts in the new history of physics. It is odd that such a view existed even 15 years before the first industrial nuclear power station was commissioned at Obninsk in the USSR. Meanwhile, as early as 1939 important theoretical papers by Frenkel, Kurchatov and Ya. B. Zeldovich were published which brought ever closer the practical solution of the problem of using nuclear energy. During World War II the German scientists Otto Hahn, Lizzi Meitner and Fritz Strassmann discovered uranium fission and Niels Bohr provided a theoretically grounded substantiation that the chain process can occur in the nuclei of the uranium isotope, Uranium 235.

When Kapitza told the staff of *Detskaya Literatura* about the difficulties involved in releasing atomic energy he was asked whether nuclear reactions could be caused by means of lesser energy. Pyotr Leonidovich replied in the following way: 'It appeared that uranium could make this possible. Scientists are now actually working with uranium. There were cases when the amount of energy expended was less than that obtained. But after calculations were made it turned out that such a reaction would require a very large amount of uranium. Then it became obvious that even

tonnes of uranium were no good; what was needed was to separate from uranium one of its isotopes. The separation of the isotope would require more energy than could be obtained by means of nuclear reactions. Well, there may be some other possibilities, but it would be quite unexpected if there emerged real prospects to use intranuclear energy. As a rule, the processes we apply in technology already exist in nature in one form or another.'

This shows that Kapitza was aware of uranium research conducted by Niels Bohr, by Francis Perrin, who tried to calculate the critical mass of uranium, and by the American researchers and engineers who were engaged in the problem of uranium isotope separation, and so on.

To the question 'Can't we expect anything from chain reactions?' Kapitza replied: 'If such a reaction occurred it could not stop, and the Earth would cease to exist... There is no complete assurance but the data available do not indicate that it is a reality. I believe that the main thing now is to learn to use the many energy sources we possess. This can be seen from the balance of solar energy on Earth.'

The question 'Could science fiction make use of the practical implications of today's theoretical predictions?' was answered like this: 'Yes, but physics offers less scope than chemistry and physiology.' It will be recalled that in those years Kapitza was primarily preoccupied with cryogenic experiments.

The threat of a nuclear reaction that might sweep the Earth was emphasized by Frédéric Joliot-Curie as far back as 1934 in the address to the Mendeleev Symposium in Moscow. Touching on the discovery of artificial radioactivity the young French scientist said that researchers who created and destroyed chemical elements at will would find a way to achieve an explosive conversion of certain elements into others – one conversion would cause several others. If such conversions started disseminating in matter a huge amount of energy would be released. The following fantastic picture could be imagined – such conversions have affected each and every element of our planet, in which case we should be faced with a horrible catastrophe. If a researcher found a way to cause a catastrophe the question was whether he would try to bring it about. 'I think he will carry out this experiment', Joliot-Curie said, 'since the researcher has a searching mind and likes the risk of the unknown.' Joliot-

Curie stressed not so much the technical as the moral side of the problem of future thermonuclear investigations.

Years passed.. Many authorities did not believe it was feasible to create a thermonuclear reactor, i.e. to effect peaceful application of the synthesis of hydrogen nuclei (protons) into helium nuclei (alpha-particles). True, it appeared that momentary thermonuclear reactions causing a very powerful detonation could be used for slow processes in power engineering. But the numerous technical impasses which researchers into thermonuclear fusion repeatedly came up against strengthened their scepticism.

One day in 1972 I reminded Pyotr Leonidovich that in the past he had firmly rejected the possibility of a practical use of nuclear energy. Kapitza remarked diplomatically that if that had been the case it was 'a mistake'. He said that in the first years of the war he already presumed it was feasible to use atomic weapons, hence, to use nuclear energy for practical purposes. Later I asked his secretary for the text of his speech at the anti-fascist meeting of scientists in Moscow on 12 October 1941 and found the following words there: 'Recent achievements provide us with fresh possibilities of using intratomic energy, which had hitherto been the subject of science fiction novels only. My personal view is that the technical difficulties facing the use of intratomic energy are still very great. It is a questionable matter for the time being, but it is quite probable that the prospects are very promising.'

I asked Pyotr Leonidovich if he now believed that it would be feasible to use thermonuclear fusion for commercial purposes. He answered in the affirmative and referred to his article in which he said that there was a design for a thermonuclear reactor.

Kapitza has long arrived at the conclusion that nuclear and thermonuclear energy is of paramount significance for the progress of mankind. He considers the use of nuclear energy to be one of the main features of the scientific and technical revolution. 'We are all aware that the implications of this revolution could be very terrible and lead to the extinction of mankind,' says Pyotr Leonidovich. 'Although we all hope that people will be wise enough to ultimately direct the scientific and technical revolution along the right path, the path that leads to the happiness of mankind...'

TO TEACH OTHERS

To teach others it takes genius,
It takes a forceful spirit.

N. Nekrasov

The Institute of Physical Problems has expanded, and the park on its grounds no longer seems as thick and large as before. New laboratory blocks, workshops, garages and auxiliary services have been added. Many physicists work at the Institute but a great deal more numerous are the engineers, technicians, laboratory assistants and highly skilled workers. The staff of the Institute can design and make the most sophisticated instruments and apparatus which modern physics requires.

Kapitza set up a large theoretical department at the Institute, which was headed by Academician Landau until his death. Since 1968 Academician I. M. Livshits has been in charge of it. At the Institute there are many young talented specialists, and credit for this is largely due to Kapitza who carries on the noble traditions of his teachers, Rutherford and Ioffe, in educating the young generation of scientists. Seminars of young physicists in which prominent scientists willingly take part are regularly held in the conference-hall. Sometimes they are attended by 100-200 people. Many participants come from other cities.

At the Institute on any day you can meet scientists who have come to talk to Kapitza or to some of his staff. Occasionally whole scientific collectives come to familiarize themselves with the work of the Institute. Some foreign scientists come to Moscow to visit the Institute of Physical Problems. They take part in seminars, make reports, participate in scientific discussions, and get acquainted with the fresh researches conducted at the Institute. In the visitor's book there are many entries in different languages, made by outstanding scientists of the world. Here you can see the

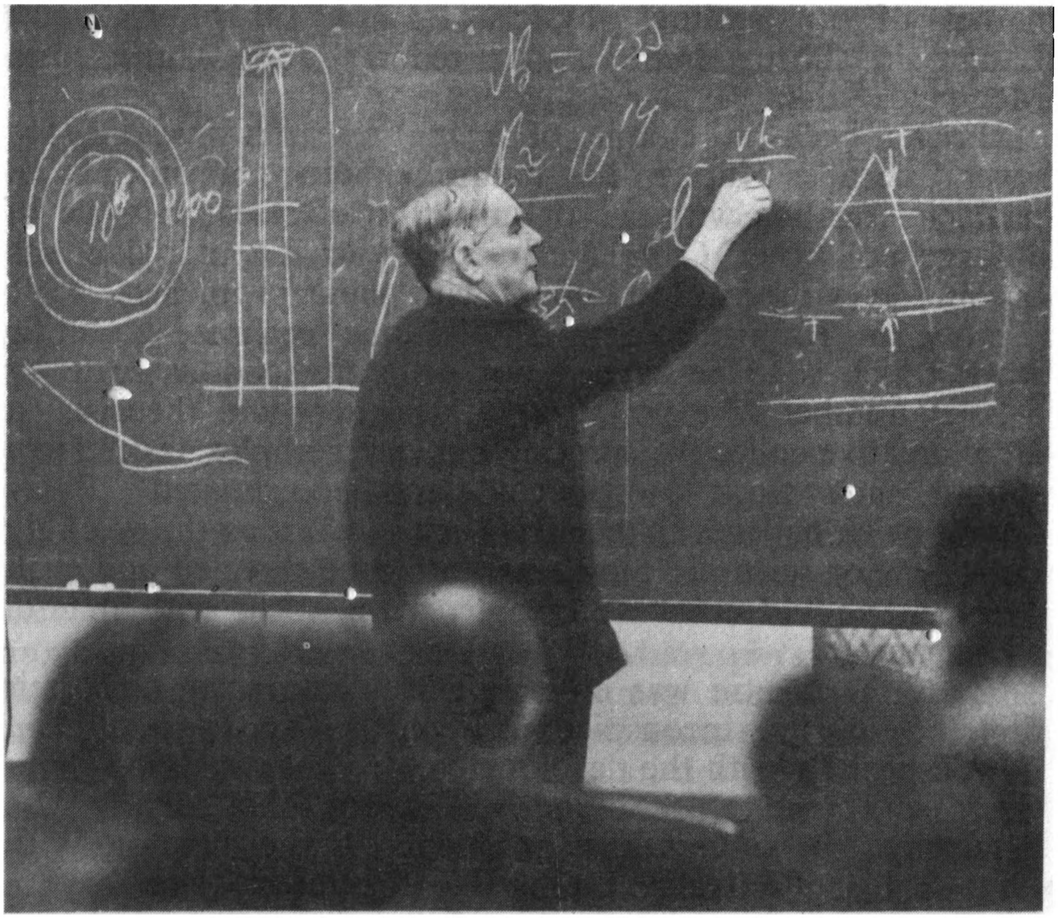
names of outstanding physicists, among them Andrade, Langmuir, Born, Irene and Frèdèric Joliot-Curie, and Meghnad Saha.

Having been in charge of a big research institute for several decades Kapitza has naturally been confronted with problems dealing with the organization of research work of a large collective. Over the years Pyotr Leonidovich has become ever more preoccupied with these problems.

How, in Kapitza's view, should one organize scientific work which is to be carried out on a tremendous scale by a large number of experimenters, designers and theorists – a large creative collective carrying out one complex task? How should such work be directed and coordinated? Pyotr Leonidovich believes that under such conditions the working out of major scientific problems should be directed and such overseers should combine great creative talent with that of an organizer.

'Once the theatre was only an actors' company, and their director was an inconspicuous figure,' Kapitza says. 'But now, especially with the development of films involving thousands and tens of thousands of actors, the person who determines the success of a production is the director. With large-scale collective research, the director is necessary in

After a lecture at the Institute of Problems of Mechanics (USSR Academy of Sciences), 1974



During a lecture

science as well. What requirements do we expect of such a person?

The main requirement is that this role should be a creative one and not merely administrative. The director should understand the meaning and purpose of scientific research, and he should correctly assess the creative potential of those working under him; he should allocate functions according to talent, and deploy his forces so expeditiously that all aspects of the problem at hand develop harmoniously...

We know instances when a great actor, such as Charlie Chaplin, was also a great director... Doubtless, however, we are now entering a period in the development of science when an increasingly important role will be allotted to the organisers of science.' (Excerpt from Kapitza's speech at the International Symposium on the Planning of Science, held in Prague in September 1959.)

'...Scientists are soldiers of an army engaged in the conquest of nature for the benefit of mankind,' maintains Pyotr Leonidovich. 'This army forms a continuous front which comprises all the fields of science and extends in all directions. The war is being waged in every country, and scientists indeed form units of an international army with a single objective – victory over nature.'

Kapitza stresses that we can see 'active fighting' in some sectors of the front and what can be characterised as 'trench warfare' in others. In the areas of intensive military activity, Pyotr Leonidovich says, there are breakthroughs and advances into new fields of science. 'These breakthroughs are usually associated with the discovery of new natural phenomena, the development of new research processes, or the creation of a new theory.' Kapitza believes that intensive activities in a given field last not more than 5-10 years. Once the intensive activity has subsided, the front reverts to a state of trench warfare, when preparations are being made for the next breakthrough.

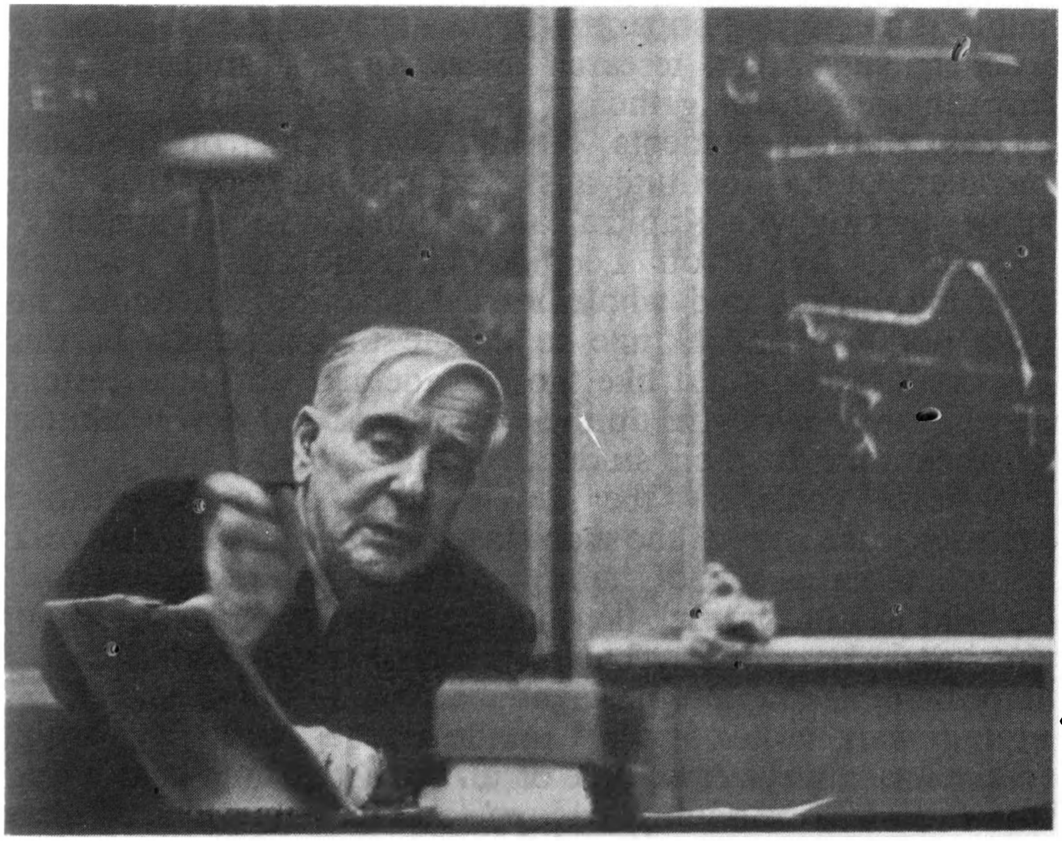
A meeting in P.L. Kapitza's study at the Institute of Physical Problems

According to Pyotr Leonidovich among the defects in the work of a scientific institute one should first of all include the moment when the collective and its leader fail to notice 'the end of active fighting' in such sectors of the front and continue to keep 'major forces' there. This means a big waste of major research forces and a 'deterioration of the scientific work of the institute.' Kapitza thinks that an institute has entered a stage of senile sclerosis if its research work is no longer focused on new frontiers in science.

All his life Pyotr Leonidovich has advocated greater capital investments in the development of scientific research and research institutions. In his correspondence with the People's Commissariat of Finance as early as the late 1930s he asked them cunningly: 'How much funding, in the Commissariat's opinion, should Isaac Newton have been given for his work which culminated in the discovery of universal gravitation? When looking at a Rembrandt picture are you really interested in the great artist's expenditure on brushes and canvas? Then why are you so interested in the cost of equipment and materials when you consider research? Fruitful research is worth incomparably more than the expenditure involved in it.'

In saying that Kapitza, of course, understood the difficulties that arise in financing scientific work and that it was practically impossible to indefinitely increase state allocations for it. In Kapitza's opinion, one of the most complicated and challenging tasks in the organization of scientific research is 'the selection of the most truly gifted young students and the establishment of conditions in which their talent can be developed to its fullest potential. This requires the ability to assess the creative potential of the young, when they are just starting their academic careers. The major common mistake here is to take their comprehension and erudition for creative capability'.

Kapitza believes that one of the most effective ways of learning how to assess the creative potential of youth is the analysis of original works by the great scientists. 'I personally learned a lot', says Pyotr Leonidovich, 'from the works of such scientists as Maxwell, Rayleigh, Curie and Lebedev; besides it gives aesthetic pleasure. Manifestations of human creative genius are always beautiful and one cannot help admiring them!' Kapitza himself considers it his duty to acquaint young people with the life of outstanding scientists,


Kapitza formally closes a session of the Institute's Learned Council, 1977

for this acquaintance helps them to be enthusiastic about the work they are engaged in, and at the same time to assess their own abilities.

The underlying idea in the scientists' biographies written by Kapitza is the necessity of raising up a young generation capable of developing science. Kapitza thinks that the personality of a prominent scientist should be characterized both by his contribution to science and by the school he has created. 'It is well-known that Rutherford was not only a great scientist but also a great teacher,' writes Pyotr Leonidovich. 'I don't know of any other scientist among Rutherford's contemporaries in whose laboratory so many prominent scientists have been trained.' Lomonosov had no pupils of his own, and in his essay about him Kapitza states with regret: 'With his exceptional imagination Lomonosov could have been the director of a large scientific school. However, the conditions for founding such a school did not exist in the Russia of that time.' According to Kapitza one of Langevin's services was that 'although Langevin's

publications were comparatively few, he was a very generous teacher, suggesting research ideas to his students, and inspiring and helping them.'

Has Kapitza students of his own? One of the staff members of his Institute answered this question thus: 'All those working with Kapitza can call themselves his students'. Despite his age Pyotr Leonidovich conducts his research with enthusiasm and whole-hearted devotion. Therefore, he does not have much time to devote to his pupils. In this respect Kapitza is not like those academics who at a certain stage of their lives give up their own work and devote almost all their time to their students.

Kapitza considers the development of one's creative abilities to be one of the main tasks of education. This work should begin at school, he says. 'This is a fundamental task on whose solution may depend the future of our civilization, not just in one country but on a global scale; this task is as important as the problem of peace and prevention of an atomic war,' writes Pyotr Leonidovich.

Kapitza always tries first of all to understand and bring out the abilities of a young person. He is convinced that these abilities, not to mention inborn talent, must be combined with such features as independent thinking, a serious approach to all aspects of life, and initiative: only in such a way can one reach the summits of science.

THE INSPIRED CREATIONS OF THE ARTS

Everything nourished his soul:
The works of sages,
The inspired creations of the arts,
The legends and precepts of centuries past,
The hopes of flourishing times.

E. Baratynsky

We often hear talk that scientists are always terribly pressed for time, and that because of their being very busy they cannot be engaged in anything but science. Because of their concern about the progress and results of research, it is said, as well as about their pedagogical duties, their ability to appreciate other aspects of life becomes blunted and they lose a sense of humour. There emerges an image of a live machine almost entirely devoid of human features and without any interest in other people. Of course, this is not so, especially when an outstanding scientist is being discussed. If you're considering Kapitza you should not hesitate to discount at once what has just been said, for it has absolutely no relation to the truth.

Kapitza has qualities that make him an extremely interesting person to deal with. The old word 'encyclopaedist' is quite applicable to him. His erudition, and profound knowledge of literature and art are astonishing. Pyotr Leonidovich is also quite at home in socio-economic problems and takes an interest in politics. He has time for everything despite the great pressure of work, and the reason is his tremendous capacity for work, and, of course, interest in life. Kapitza himself says that giftedness alone without the capacity for work does not as a rule yield tangible results. Pyotr Leonidovich has a good sense of humour, appreciating it in others, too.

All his life Kapitza has been friendly with artists, actors, writers, and journalists. Among his friends have been the artist Mikhail Nesterov, the sculptor Vera Mukhina, the writers Alexei Tolstoy, Vsevolod Ivanov, Mikhail Prishvin, as well as Irakli Andronnikov and many others.

Kapitza with the film director A. P. Dovzhenko (centre) and the sculptor S. T. Konenkov, 1955

To my mind, for several decades now Kapitza has been trying to bring the exact sciences and the arts closer together. Thus, he has interrogated Andronnikov: 'How many new lines by Lermontov have you found in the course of your life? I ask this because interpretations can change, but Lermontov's text will never change.' Pyotr Leonidovich also asks Irakli Andronnikov whether he attributes his literary finds to sheer luck or whether he has some system which he follows in his work. 'Who has suggested to you the idea of using detective methods in literary studies?' he keeps on asking.

In 1930 Sergei Eisenstein, a young but already famous film director, visited Cambridge. He met Kapitza and saw his installations in the laboratory. Pyotr Leonidovich wondered what impression the work had made on the film-maker. This is what Eisenstein wrote about this meeting:

'I first met Pyotr Leonidovich Kapitza in Cambridge. He was then a Fellow of Trinity College and wore a black gown. He showed me round his laboratory where there were

only two things I understood, namely, that there was an electric machine powerful enough to light about half of London, and that this entire energy was directed on a patch several millimetres in size.

The machine, I thought, had something to do with the early experiments in splitting particles of matter.

But it wasn't either the machine or matter itself that interested me.

What did intrigue me was an approach to the role of time which Pyotr Leonidovich explained to me.

I mean brevity of time! This is a means of protecting oneself from the incredible temperature which inevitably accompanies the application of tremendous amounts of energy.

This energy is switched on for such a short time that only its "main" effect in which the experimenter is interested can be realized, and the accompanying phenomena, such as enormously high temperature, have no time to have an effect.

I am not sure that my description is accurate, but I caught the "principle" itself in precisely this way, and it could not be obliterated from my memory either by the solemnity of the subsequent dinner at 'high table' in the company of professors and the master under the high gloomy vaults of the hall's gothic naves, or by the Latin antiphonal two-part graces read before meals, or by any other whims and charming details of my three-day stay amidst the Cambridge colleges...'

The celebrated film director had described the principle of the pulsed method of obtaining strong magnetic fields in a rather peculiar way, but did not escape, of course, some inaccuracies odd from the viewpoint of a physicist. But nevertheless Eisenstein understood the idea of the method.

It is of interest to note that Eisenstein's visit to Cambridge was later reflected in his film 'Ivan the Terrible'. Discussing the film Eisenstein recalled:

'I do not remember how it occurred to me to use this two-part grace. But I think that it dawned upon me as a result of quite a real living impression, the first time I heard such antiphonal two-part praying...

This was in Cambridge.

In 1930.

In Trinity College.
In the huge Tudor dining-hall.
Although I sat (or rather at that moment I stood) next to such a powerful supporter of the materialistic unmasking of nature's mystical secrets as P.L. Kapitza (who was then working in England) there it was, nevertheless,... a Latin grace before the meal...
All this was the last thing in my mind when I included in the script of 'Ivan the Terrible' the scene showing Ivan over Anastasiya's coffin. But now I think that this episode of the film is certainly linked with the living impressions of that remote evening in pre-war England.'
The writer Mikhail Mikhailovich Prishvin made the following entry in his diary after meeting Kapitza: 'In the past we thought that the atom is a simple, infinitesimal quantity of matter, but now we have found that the atom is a tiny universe. Similarly, we, engineers of human souls, have realized that the atom of human society [man] is also a tiny universe and that each spiritual nucleus is surrounded by a definite large number of ape-like essences with which the spiritual nucleus is linked by a sense of duty. Atomic energy in a human heart is called freedom, and a revolution fully corresponds to the release of intratomic energy. But probably the ratio between the free nucleus spirit and the subordinate ape-like essences, one which we call order, is the highest idea of atomic being and precedes any creative activity; by developing in man's conscience it forms, on the one hand, our core essence of harmony, and, on the other, the idea of space and time.'
It can be assumed from the above that during his talk with the writer Kapitza not only set forth the essence of the works of Rutherford and other physicists on the planetary model of the atom, but also told him of Aldous Huxley's fantastic Utopia *Brave New World* which he had been able to read in English (at that time the Russian translation of the novel did not exist).
In his recollections about Prishvin Pyotr Leonidovich wrote:
'Any creative activity, both in science and art, is born of man's dissatisfaction with reality. A scientist is displeased with the existing theory and level of knowledge in his field of science; a writer is usually discontented with the existing conditions of people's lives, with the ethics of their mutual

relations, and often with the social structure. In the case of a visual artist it is aggravated by dissatisfaction with the generally recognized and current ways of reflecting the surrounding world.

As great creative work is linked with the philosophy of transforming the world and is inevitably based on dissatisfaction with the existing order of things, this leads to the works of writer-thinkers, such as Tolstoy, Dostoyevsky and Gorky being considered by the established social order as factors interfering with the peaceful flow of life, and they usually provoked active disapproval on the part of the Establishment.

This inevitable contradiction between creative quests and the existing social set-up is the dialectics of progress in human culture. These contradictions between creative activity and human reality put scientists, writers, artists, philosophers – and creative professions in general in all the fields connected with the mental and spiritual growth of mankind – in the position of fighters. And struggle is generally linked with privations, frustration and other trials. But if these contradictions between creative work and real life did not exist human culture would cease to develop. Since the law of dialectics is always applicable these contradictions will exist in one form or another under any developing social system'.

Kapitza became acquainted with Prishvin at the writer's dacha early in July 1949. The acquaintance grew into friendship. 'I often met M. M. until his death in 1954,' Pyotr Leonidovich recalls. 'On the eve of his death we were at his Moscow apartment. I knew that M. M. was incurably ill, but that evening M. M. was, as usual, communicative and talked about music which he was fond of. He fetched a gramophone and some long-playing records which had just come on sale, and we listened to classical music. We scanned Prishvin's stories and novellas which had recently been put out in English translation in England. We had supper together and emptied a bottle of dry wine. The only unusual thing that evening was when he was seeing us out. In the hall, where we would often have most interesting discussions before parting, M. M. sat down on a chair. The next morning Valeriya Dmitrievna rang up to tell us that M. M. had died during the night.'

Kapitza believes that Prishvin's diaries reveal with particular force the 'contradictions between his ethical and social concepts and the existing world'. Pyotr Leonidovich remarks that 'everything M.M. wrote about always contained the question of man's ethical relationship both with his natural environment and with the society he lives in. Here he considered the "joy of personal freedom" to be the main criterion of human happiness.'

Kapitza was on friendly terms with the wonderful Russian sculptor Sergei Konenkov who has made sculptural portraits of many outstanding figures in science and the arts. In his book *Moi vek* (My Century) (1971) the sculptor told about his meetings with the prominent scientists who had sat for their portraits. 'Scientific ties' kept on expanding: 'Pyotr Leonidovich Kapitza called on me once to have a look at Einstein's portrait,' Konenkov writes. 'For my part I told him of the interest Albert Einstein had taken in the works of the Soviet theorist Kapitza.* I visited Kapitza several times. And I dreamed of making a portrait worthy of his name; I made preparations and scrutinized him, but time passed. The portrait was destined to remain in my head. Indeed, the old maxim is right: do not put off till tomorrow...'

There is a well-known anectode that a British firm once asked Kapitza to eliminate the malfunctions in a new electric motor, which for some unknown reason would not work. Kapitza examined the motor thoroughly, switched it on and off several times, and then asked for a hammer. Giving it a moment's thought, he struck it with the hammer and – lo and behold! – the motor began to work. For this consultation the firm had paid Kapitza a £1,000 advance. An official of the firm, on seeing that it only took a few minutes to put the motor right, asked Kapitza to produce a written account for the money received. Kapitza wrote that he believed the hammer blow was worth one pound, while the remaining £999 had been paid to him because he knew exactly where to strike.

A respected and well-known scientist, after reading this anecdote, doubted if it was correct. In his review of the

* Obviously, Konenkov, like Einstein, called Kapitza a theorist.

manuscript he pointed out that '...according to Kapitza himself, the anecdote is about Parsons, the well-known designer of steam turbines, (rather than Kapitza as the author maintains), and the sum mentioned in Kapitza's story was £500. Of course, it is not the sum but the doubts as to the authenticity of the author's other assertions that matter.' However, in this case I decided to leave the text as it was, certainly apologizing to the reviewer and my readers. Such anecdotes are generally attributed to many people, and their particulars often change (in this case the sum of money). It is in this very form that I have heard this anecdote narrated for decades; moreover it has been printed several times. It should be remembered that this is only an 'undergraduate' anecdote and that is why, risking to shake my readers' trust, I have used this merry story to describe Kapitza's real character.

You could say that Kapitza always knows where to 'strike' to obtain the desired result. This principle is also applicable when trying to find a way out of a complex situation without sacrificing one's convictions in the process. Kapitza is firm and never sacrifices his convictions. It is this attitude to life that has made him invulnerable to blows.

Kapitza values in people a bent for some occupation, for what has recently been called a 'hobby'. In his recollections about Langevin he was pleased to note that the French physicist had a knack for wine-making and wine tasting. Once Kapitza gave instructions to display on the Institute's notice-board a 'document' entitled 'The culture of wine drinking'–a lengthy paper compiled by a staff member, a physicist from a family of hereditary wine-makers. It may be assumed that Kapitza took pleasure in reading the following line of this long and elegant code of laws about wine drinking: 'The Russian artist Kiprensky (the painter of a portrait of Pushkin) would put a candle in front of himself when he drank wine, and, before actually drinking it, he would hold it against the light for a long time. "It is a pity, my dear," Kiprensky once said to the famous Russian engraver Iordan, "that you cannot paint pictures with wine. How much light and excitement we would then put into our creations."'

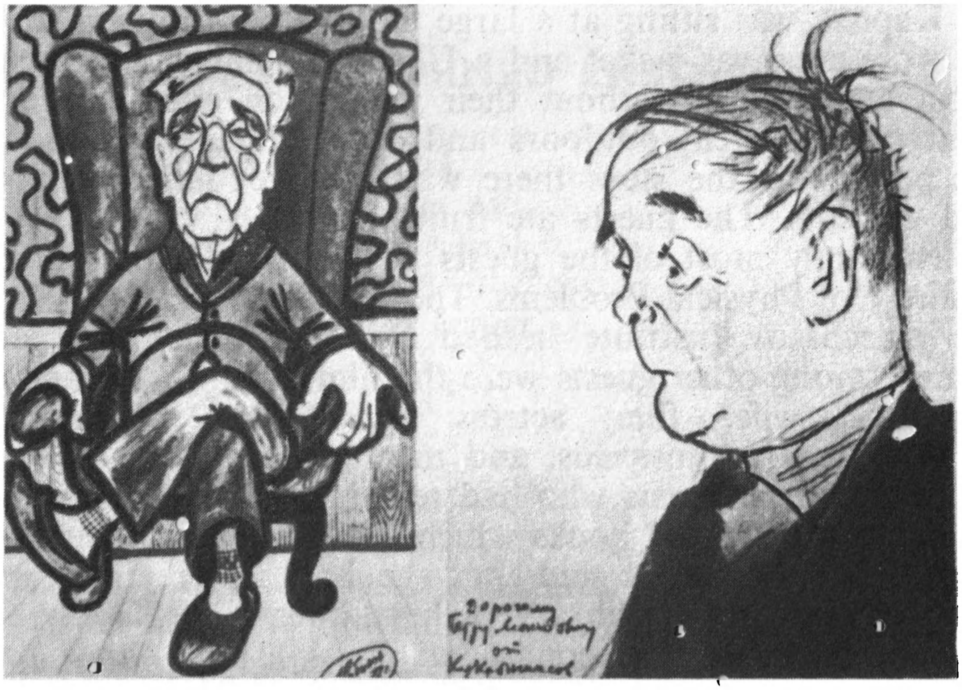
Thinking about properties of wine Kapitza paid attention to the professional sensitivity of wine tasters, which is higher than that of the most sophisticated physical instruments. In

the late 1950s radioactive analysis was considered to be the most sensitive method for determining inorganic impurities. In this way one can detect impurities in the doze of one part per 10^8 to 10^9. Yet it turned out that a dog can detect much smaller quantities of impurities and identify them. One may ask why man has not devised other instruments comparable in sensitivity to the smell organs of the dog. Kapitza answers this question thus: 'As is known the olfactory organs are the most complex of all the sense organs, and the nature of the phenomena on the basis of which they function has not yet been discovered. Thus, "to equal the sense of smell of a dog" is one of the problems for physicists in the future.' This is an excerpt from Kapitza's speech at the International Symposium on the Planning of Science held in Prague in 1959.

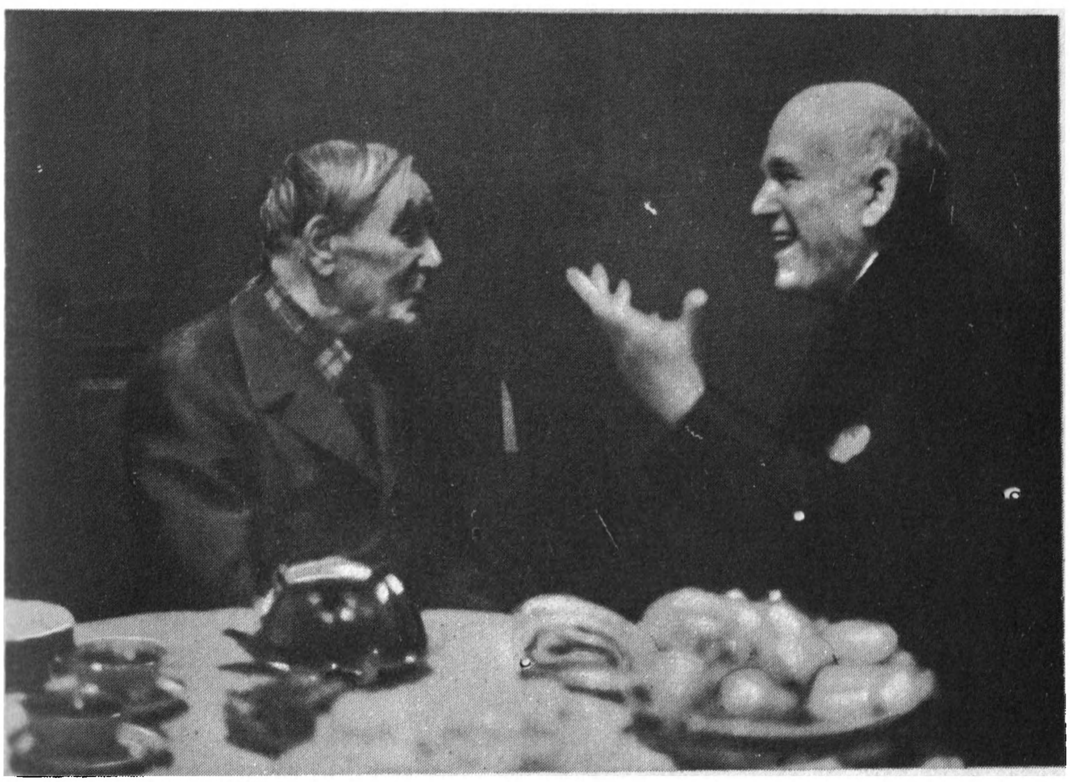
The upper hall of the Institute of Physical Problems is often used for the exhibition of pictures by artists belonging to different schools. Once a display of marvellous photocopies of well-known works by Russian artists was arranged there. Kapitza tries to facilitate the acquaintance of scientific workers and students with good pictures by modern artists. In this he is assisted by a great lover of painting Pavel Evgenyevich Rubinin, brother of the young talented artist Aleksandr Rubinin.

In Kapitza's study hang several water-colours of himself. At first glance they might appear to be caricatures. But Pyotr Leonidovich says that the drawings made by Boris Livanov, the famous actor of the Moscow Art Theatre, are neither caricatures nor cartoons; they are an original way of rendering the image and character of the person depicted, and testify to Livanov's talent as an artist. Livanov said about his old friend: 'I have known him for a long time and have always admired this man, the complexity and unusual wealth of his nature, and his sparkling wit.'

Kapitza invited me to his birthday party, and I went to Nikolina Hill to see him. I went there by bus from Perkhushkovo railway station through a thick pine wood. At my request the driver made a stop at the asphalted road leading to Pyotr Leonidovich's dacha. Another half a kilometre and I was at the open gates of his country house.



P. L. Kapitza: affectionate caricatures by Aleksandr Rubinin (left) and the artists 'Kukryniksy' (Kupriyanov, Krylov and Nikolai Sokolov)



Kapitza with the pianist Sviatoslav Richter after a concert at the Pushkin Museum of Fine Arts, Moscow 1980

Kapitza was sitting at a large table in the drawing room. He wore a canvas jacket and a Ukrainian embroidered shirt. Most guests (men without their jackets on and women in light dresses) went outdoors and seated themselves around the porch. On the steps there was a basket full of oranges and apricots. The guests ate fruit and talked.

Naturally most of the guests were staff members of the Institute of Physical Problems. Thermonuclear scientists from the Kurchatov Institute headed by Artsimovich had also come. Among other guests were the film director Alexandrov and his wife, film actress L. P. Orlova, cosmonaut V. Sevastyanov, musicians, and men of letters.

Some of the guests who had remained in the rooms took an interest in the old books which occupied a small separate rack. Anna Alexeevna said that the books were in French and belonged to the library of her father A. N. Krylov. He had been fond of second-hand book shops and their confusion, and would rummage for a long time through their books. There were very valuable editions among those he had bought.

The celebration lasted till late at night. Early in the morning Pyotr Leonidovich went to the Institute in his old, Academy's ZIM as usual.

HOURS OF DETERMINED LABOUR

The single joy is work
In field, at bench, and table:
Work till the sweat runs hot,
Work without counting the cost,
Hours of determined labour.

V. Bryusov

Another two years passed. Kapitza was honoured on the occasion of his 80th birthday and awarded the second Gold Star Medal of a Hero of Socialist Labour and the Order of Lenin. At his birthplace in Kronstadt a bronze bust of him was erected.

On that day his dacha on Nikolina Hill was visited by his numerous friends, pupils, admirers and representatives of different organizations. The cheerful voices of students from the Physico-Technical Institute could be heard under the old roof.

At the table laid in the orchard were M.V. Keldysh, the then President of the USSR Academy of Sciences, and Academicians A.P. Vinogradov, A.N. Frumkin, V.A. Engelgardt and Yu.B. Khariton. With a microphone in his hand Sergei Kapitza introduced the speakers to the guests. Among those who spoke were not only famous physicists, mathematicians, chemists and geologists. Irakli Andronnikov said that he also considered himself to be Kapitza's pupil, and offered arguments proving Pyotr Leonidovich's influence on literary criticism; the celebrated chess player Vasily Smyslov caused jollity by saying that Pyotr Leonidovich, despite his being preoccupied with physical experiments, would once in a while find time to play a game of chess – and then the world ex-champion would have a dangerous competitor.

Then it was Kapitza's turn to thank the guests for their cordial greetings. He took the microphone from his son and said that he introduced the 'correction factor' to the compliments addressed to him and added laughingly: 'For all that, it is pleasant to listen to. It is good when you are

Kapitza with a friend from Cavendish days, the Australian physicist Mark Oliphant. Moscow late 1960s

Kapitza with Lev Davidovich Landau, some months before the latter's death, 1968

valued not only by your fellow scientists but also by the management.' This humorous admission made in the presence of the President of the Academy of Sciences prompted a merry response on the part of those present.

A talk with participants of the Colloquium in Moscow to commemorate Rutherford's birth centenary, August 1971. Next to Kapitza are N. Feather and S. Devons, former students of Rutherford in Cambridge

P. L. Kapitza and J. Cockcroft, a sketch by Swedish artist M. Silvan

Kapitza with Paul Dirac at a conference of Nobel laureates, 1979

Pyotr Leonidovich did not speak long. In conclusion he admitted that he experienced a feeling of sorrow because his dear friends Lev Davidovich Landau and Lev Andreyevich Artsimovich had passed away. 'They would always come to see me on my birthday,' he said. 'And they always tried to make this day a joyful one. I must say they were a great success in this.'

The guests left late in the evening. The old dacha on Nikolina Hill which had seen so much in its lifetime became deserted and sank into sleep.

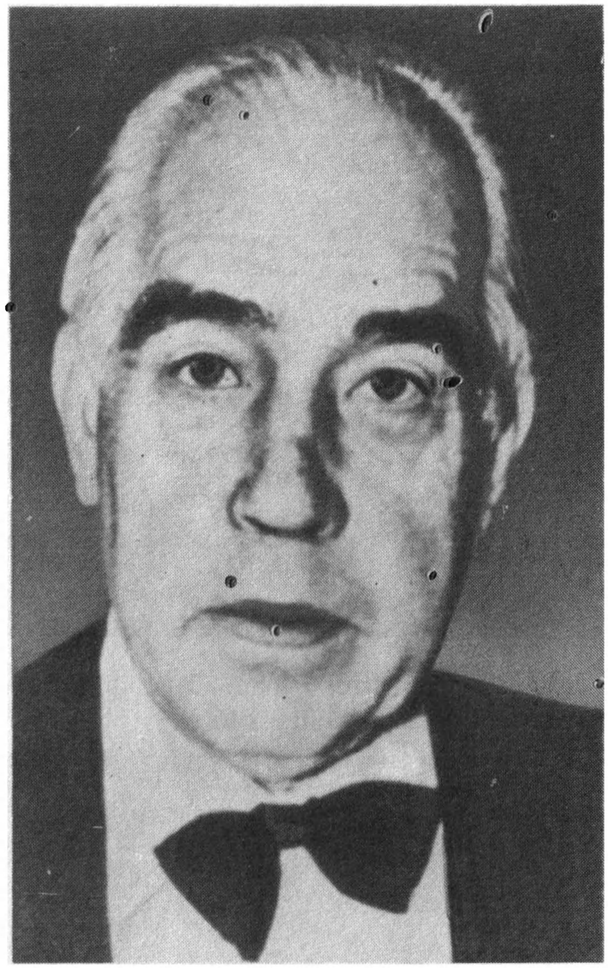
New generations may think that the discoveries of X-rays by Roentgen, of radium by the Curies, of the atomic nucleus and its major properties by Rutherford, of liquefaction of helium by Kamerlingh Onnes, of the theory of relativity by Einstein, and of quantum mechanics by Bohr were made very long ago—almost in prehistoric times. For Kapitza these events are not fenced off by an impenetrable wall of time.

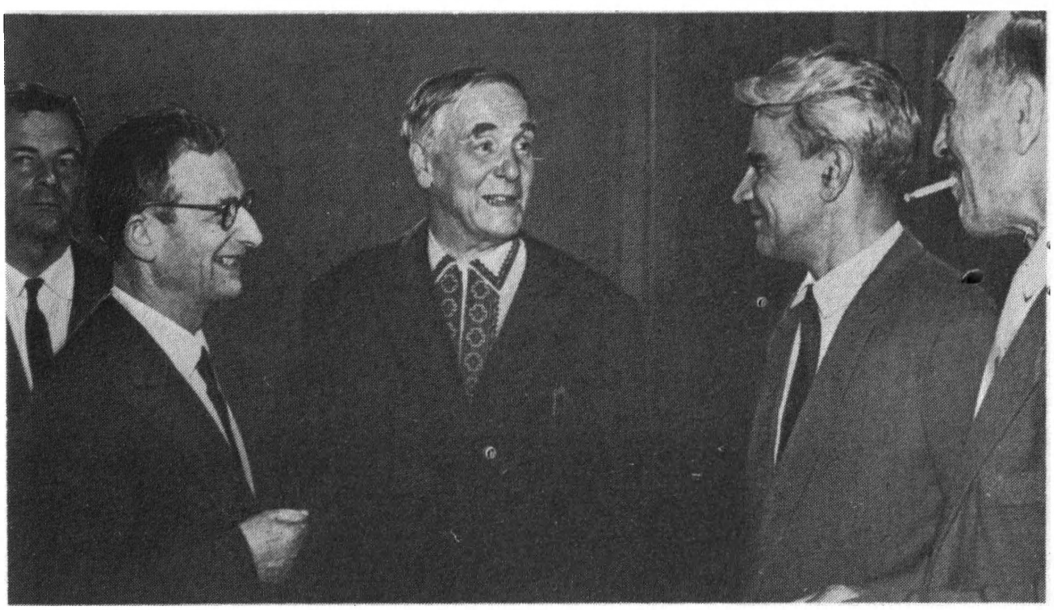
The film actress L. Orlova congratulates Kapitza on his 80th birthday, 9 July 1974. On her left is film director G. V. Alexandrov, and next to Kapitza are his sons Andrei and Sergei (standing)

Cosmonaut Sevastianov greets Pyotr Leonidovich on his 80th birthday, Nikolina Hill, 9 July 1974

Kapitza with Kurchatov and Ioffe at the Presidium of the USSR Academy of Sciences, Moscow 1959

Niels Bohr (1885-1962)





Academicians Artsimovich, Khariton, Keldysh (then President of the Academy), and Semenov (from left to right) greet Pyotr Leonidovich on his 70th birthday, 9 July 1964

Taking a stroll, 1977

accidents at nuclear power stations are fraught with great danger. The probability of an accident at nuclear power stations built in the USA had been estimated by the designers of the reactors at one thousand millionth of a percent. Then the reliability of this kind of estimate was thrown into doubt by an accident which occurred at the Browns Ferry nuclear power station in California in March 1975, but a catastrophe was luckily averted. Three leading reactor engineers have now left the employ of the General Electric Company because morally they do not feel able to take the responsibility for the safe operation of existing nuclear power stations in the USA.

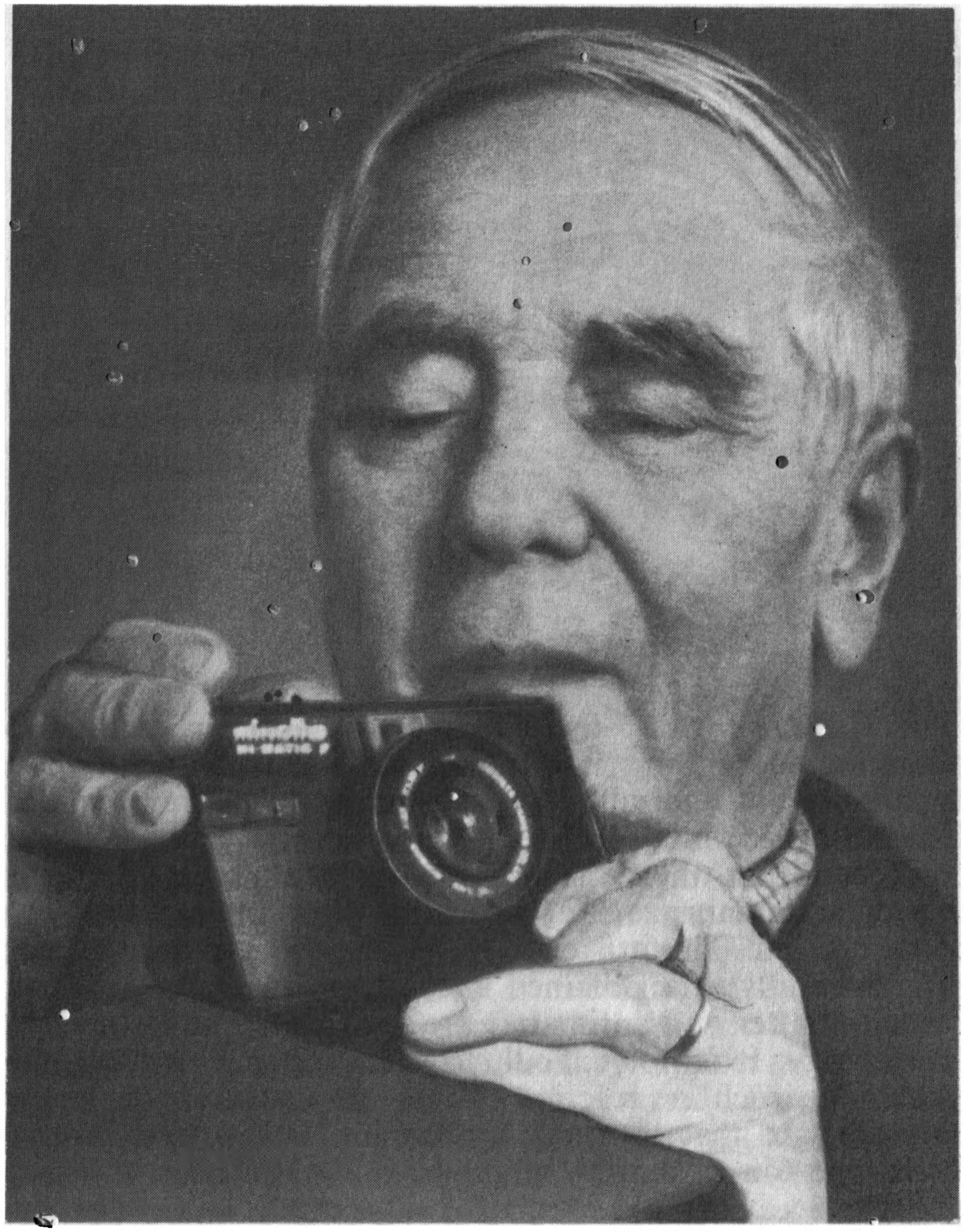
Speaking in Stockholm Kapitza confidently stated that the global problems of high power engineering cannot be resolved without nuclear energy.

Scientists of the whole world are now seeking ways to tackle the task of using thermonuclear fusion for peaceful purposes. The great successes of Soviet specialists in this field are widely known. 'I personally think', Kapitza writes, 'that controlled thermonuclear fusion will be implemented in due course.'

Pyotr Leonidovich with his great-grandson Petya, 1979

In Kapitza's view, there exists still another method of obtaining energy, but it is rather fantastic. In practice it is apparently not realizable, but scientifically it is well founded. On the basis of our present concepts of cosmogony it is considered that when our universe was being created another one of a similar size but consisting of antimatter was also being created. The existence of antimatter has been proved experimentally; it is obtained in accelerators. On coming into contact matter and antimatter are annihilated and converted into energy. It is not difficult to calculate that one gram of matter in such a reaction yields an amount of energy equivalent to that obtained by burning 10,000 tons of coal. Thus, one ton of matter would be quite sufficient to supply the whole earth with energy for a year.

But how can this antimatter be obtained? It has been supposed that a small amount of antimatter could penetrate into our cosmic space in the form of antimeteorites. Space is highly rarified, therefore the collisions of antimeteorites with atoms of matter would be rare. By capturing antimatter from space with the aid of satellites so that it does not come into contact with matter, and bringing it to earth we could have the most perfect source of energy. But attempts to find antimatter in cosmic space so far have not met with success. Experience teaches us, says Pyotr Leonidovich, that



Amateur photographer

a number of processes which were regarded as improbable have nevertheless been put into practice. One should not forget this.

However, in Kapitza's opinion, effective solution of global problems, including the energy one, will become possible only if their significance for the fate of humankind becomes widely understood by all countries. Kapitza – a representative

Turning parts for a clock

of Soviet science fighting for a lasting peace on Earth – is confident that peoples and states will find ways of solving global problems to ensure the happiness of mankind.

When the manuscript of the book was completed I had

P. L. Kapitza and the Queen of Sweden at the banquet held during the 1978 Nobel Prize-giving ceremony in Stockholm

a lucky opportunity to meet Kapitza before he left for a holiday in Kislovodsk.

I came to see him at the Institute of Physical Problems. After a short business talk I asked him from sheer force of journalistic habit:

'They say you work in the laboratory for long hours. What are you preoccupied with now?'

'With thermonuclear research,' Pyotr Leonidovich answered and added: 'It proved interesting and I decided to go on with it.'

'Do you think a thermonuclear reactor will be built in the 20th century?'

'Many years will have passed before the century is over.'

I wondered whether Kapitza's experiments were based on the idea of plasma filament in a high-frequency field.

'The idea of plasma filament', Pyotr Leonidovich said, 'has not discredited itself. There are serious grounds in favour of continuing experiments. But I cannot yet speak with certainty about the success which would make it possible to effect the transition from physical experiments to engineering problems.'

On 17 October 1978 the Swedish Academy of Sciences in Stockholm sent the following telegramme to Pyotr Leonidovich Kapitza:

'Dear Academician Kapitza,

I have the pleasure to inform you that the Royal Swedish Academy of Sciences today has decided to award the 1978 Nobel Prize for physics in two equal parts. One to you for your basic inventions and discoveries in the area of low temperature physics, and the other to be shared equally between Dr. Arno Penzias and Dr. Robert Wilson (USA) for their discovery of cosmic microwave background radiation.

K. G. Bernhard, Secretary-General.'

Kapitza's outstanding work in low temperature physics has been highly valued and recognized by the world scientific community. The Soviet scientist has become a Nobel Prize winner in physics.

TOWARDS PERFECTION

Who will make the task less complex?
And who will clear the million roads
That finally lead to perfection?

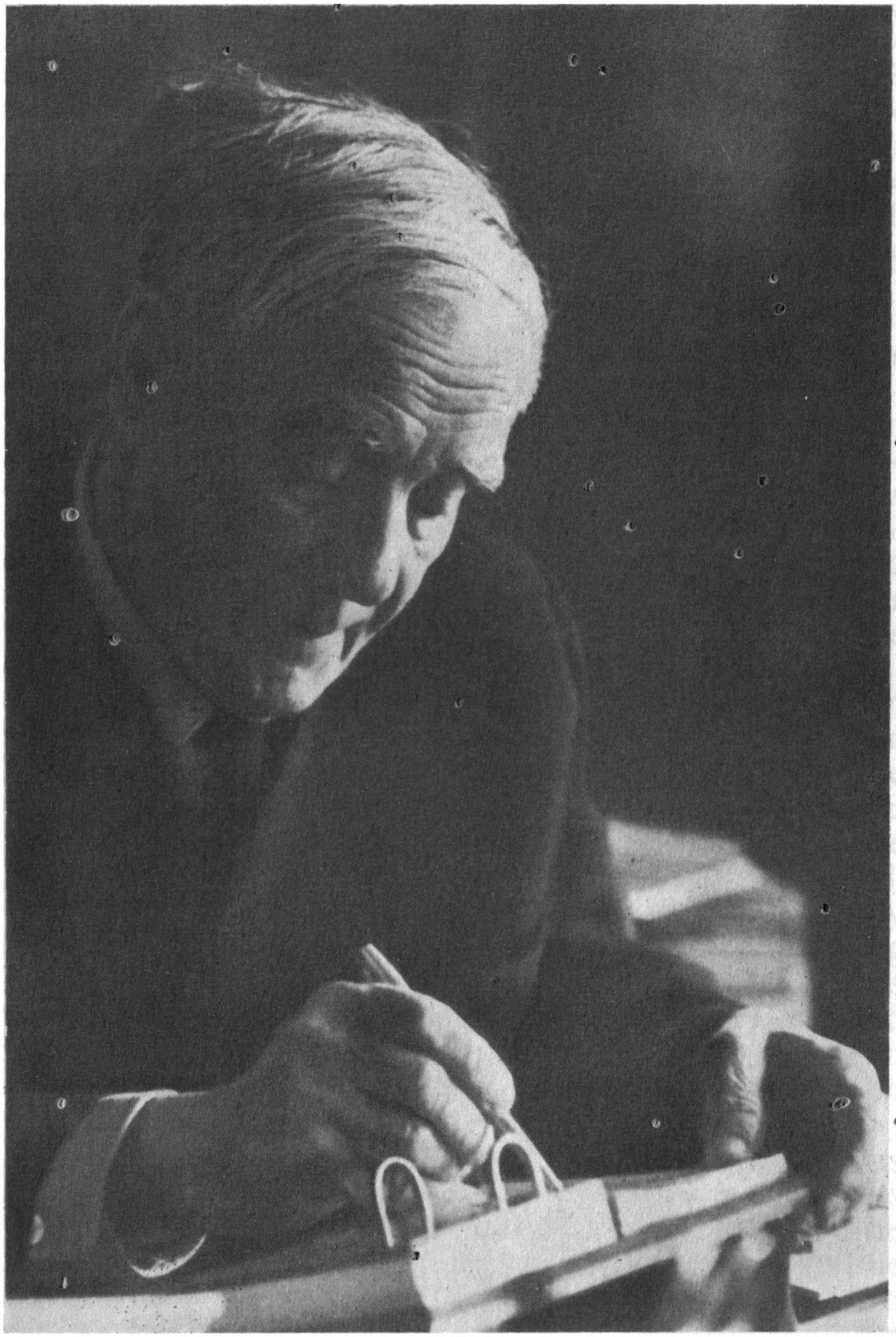
Ya. Polonsky

Over forty years ago Academician V.I. Vernadsky wrote to Academician N.G. Bruevich, Chief Learned Secretary of the Academy:

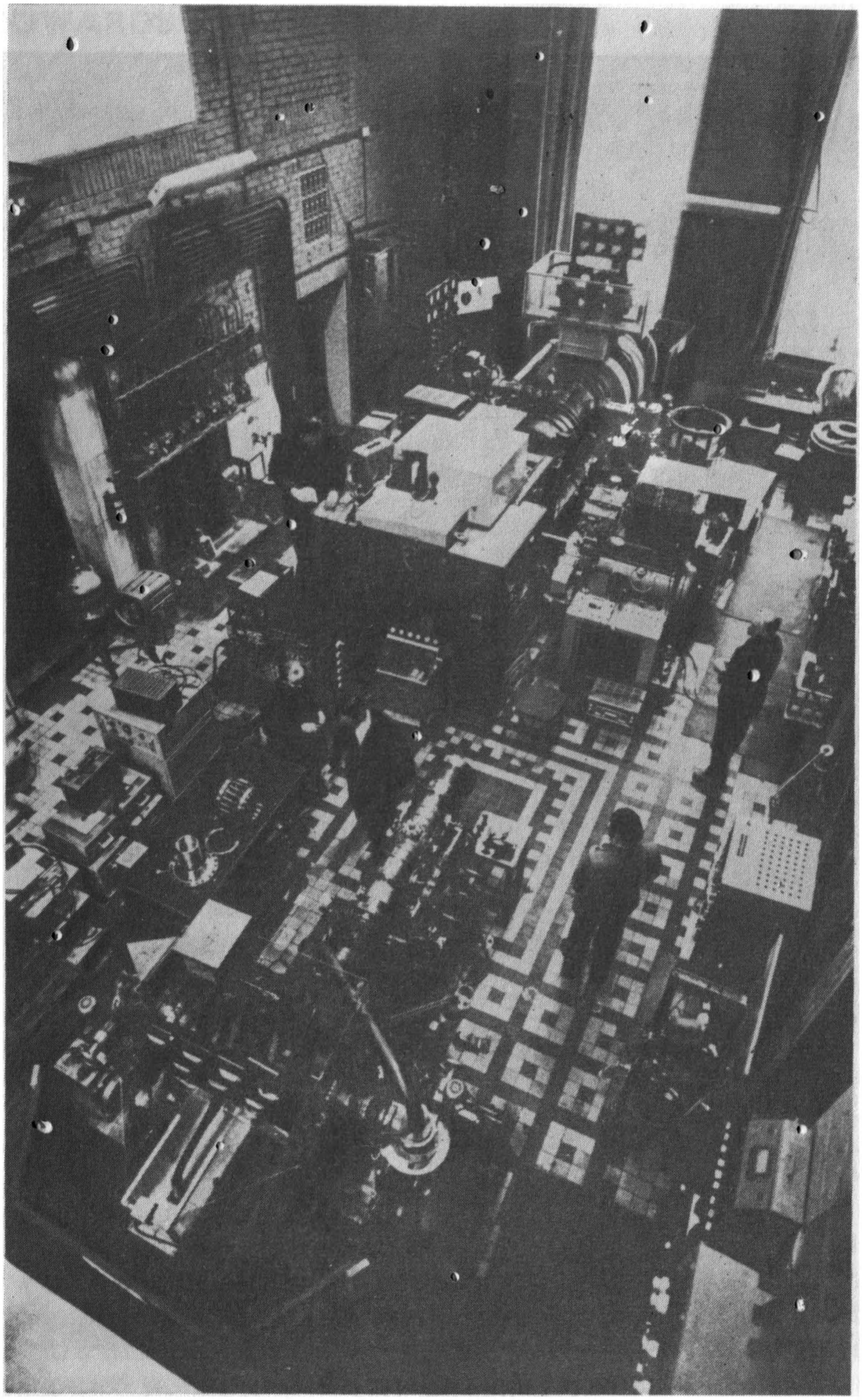
'I believe that only two institutes of our Academy are up to contemporary standards in scientific equipment and can easily keep pace with the times. I mean Kapitza's Institute and the Pavlov Institute. All the others fail to meet present-day requirements in equipment, despite the fact that their personnel have the giftedness and capacity for work that would otherwise allow for a rapid increase in their scientific productivity. Only then might our victory on the scientific front be ensured...'

After the war scientific research institutes were gradually re-equipped with much more modern equipment, and many of them were now not inferior to the Institute of Physical Problems (which had hitherto been declared second to none by many Soviet and foreign scientists including Vernadsky). Present-day Soviet institutes are equipped with intricate instruments and machines for physical experiments, as well as for research into hot plasma. Nowadays no one is surprised to see leviathans of experimental technique, such as the gigantic accelerators of elementary particles. The most sophisticated devices are skilfully operated by experimental physicists who are often called "wonder-workers".

I would very much like to finish this book about Kapitza by describing the solemn commissioning in the USSR of the world's first thermonuclear reactor, and its connection to the integrated power grid. Of course, this act would take place in the presence of Pyotr Leonidovich: he has been a tireless seeker of ways to create a practical thermonuclear power



P. L. Kapitza, 1974



Kapitza's laboratory in the Institute of Physical Problems, 1978

station similar to an ordinary uranium atomic power station which has now almost become a commonplace (even though aspects of it can still astound the imagination). Alas, at the time of writing such a triumph exists only in the author's imagination. We have not yet learned how to keep the continuous thermonuclear reaction under control as easily as we have mastered the chain reaction which occurs in the reactors of atomic power stations, these same reactors which are now 'factory-made' and were earlier called 'atomic boilers'.

In his Nobel lecture Kapitza said:

'Intensive research on fusion is done in many countries and is connected with fundamental studies of high-temperature plasmas. That fusion is possible is well beyond doubt since it actually takes place in the explosion of hydrogen bombs. The detailed theory concerning fusion nuclear reactions is in agreement with experiments. But in spite of the great effort and the large sums of money spent up to now, it is still not possible to conduct or control the process of fusion so as to make it a useful source of energy. This certainly is a cause for some bewilderment.'

When physicists began investigating the fusion of hydrogen nuclei into helium nuclei many scientists thought that the thermonuclear reactor to be based on this process would be designed within a relatively short time. But decades passed and it became obvious that it was not at all simple to tackle this task and would take much more time than was expected. There arose new, often unexpected problems which nobody could have foreseen. But in Kapitza's opinion, overcoming the difficulties that arise in the process of research makes scientific work especially attractive. True, the path leading to the attainment of a given goal becomes longer, but it often enriches a researcher with valuable knowledge and can even promote important new discoveries.

When work on controlled thermonuclear fusion (CTF) was just beginning Academician Artsimovich realized its incredible complexity better than anybody else and wrote the following aphorism: 'Any hope for a quick solution of the CTF problem is just like the hope of a sinner to get into paradise without first passing through purgatory.' The wandering of Artsimovich himself in the scientific research 'purgatory' resulted in a brilliant creation – the development of the Tokamak research programme widely acclaimed

throughout the world. (The name 'Tokamak' now accepted in all languages of the world was first proposed by Professor I.N. Golovin who started work on fusion research jointly with Academician Artsimovich when Kurchatov, the pioneer of that work, was still alive; the acronym consists of the first syllables of the following words: "toroidalnaya kamera" and "magnitnaya katushka"–toroidal chamber and magnetic coil.) The prominent US scientist Glen Seaborg recalls the luncheon at the Belgian Embassy in Switzerland, when Artsimovich told him that practical application of thermonuclear energy would begin at the turn of the 21st century at the earliest. That talk took place in September 1971 in Geneva during the 4th International Conference on Peaceful Uses of Thermonuclear Energy: Artsimovich then read a paper on the Tokamak research programme.

The difficulties confronting the researchers working on high-temperature plasma and the designers of corresponding devices do not allow us to make reliable forecasts as to the time necessary to create the long-awaited thermonuclear reactor. Academician V.L. Ginzburg wrote that in the 1970s the investigation of controlled thermonuclear fusion was not only a purely physical (viz. scientific-research) problem but also a technical problem on an industrial scale. However, Ginzburg stated that physics research was still more important, since the most efficient principles and methods of plasma confinement had not yet been found.

In the 1980s this problem continues to be unresolved. On 31 January 1979 the eminent physicist, Academician E.P. Velikhov (later elected Vice-President of the USSR Academy of Sciences) wrote in *Literaturnaya Gazeta:* 'Perhaps, in five years or so the feasibility of thermonuclear fusion will be proved, i.e. required temperatures and densities of plasma will be obtained: the thermonuclear reaction will be "ignited"'. Obviously, the extreme caution of this forecast was due to fresh problems that had confronted the researchers. But the peculiarity and fascination of any scientific discovery is that it cannot be accurately forecast, let alone planned, or else a given discovery would not be made. Of course, Kapitza was eager to see as soon as possible the practical results of the research he and his colleagues (in the USSR and abroad) had conducted for many years. Will it appear soon, this fabulous machine of the future, a thermonuclear reactor?

In September, 1981 the 10th European Conference on Controlled Fusion and Plasma Physics was held in Moscow. Physicists from many European countries and also scientists from Australia, Canada, India, Japan, and the USA gathered there. In an interview with a TASS correspondent Professor F. Engelmann, Chairman of the Division of Plasma Physics of the European Physical Society, said: 'I, for one, was deeply impressed by the work of P. L. Kapitza, accomplished at the Institute of Physical Problems of the USSR Academy of Sciences.'

A black Mercedes would take Kapitza to the conference meetings. At one of them he made a 45-minute report on his research into the plasma filament. Kapitza's paper aroused great interest.

After the conference had ended E. P. Velikhov said: 'Considerable headway has been made in the world in the field of fusion, above all in the USSR, the USA, Japan and a number of other countries. It is noteworthy that some laboratories have begun investigations into thermonuclear plasma at temperatures reaching tens of millions of degrees.' It will be recalled that during his first experiments with plasma filament started as early as the 1950s on Nikolina Hill Pyotr Leonidovich obtained a hot plasma filament whose temperature was a 'mere' one million degrees. It was then hard to imagine such a high temperature, just like that near absolute zero in the amazing phenomenon of superfluidity of liquid helium, discovered by Kapitza.

Academician Velikhov also said that obtaining of extremely high temperatures is leading scientists to the design of new large-scale installations, such as T-15 in the USSR, TETR in the USA, Tokamak, JT-60 in Japan and the 'Jet' accelerator being designed by scientists in European countries. 'Controlled fusion is developing', Velikhov went on, 'not only in the direction adopted in the USSR and known as the "Tokamak concept". Progress has also been made in alternative directions. The staff of the Livermore Laboratory (USA) and the physicists of Novosibirsk are making the greatest contribution.'

Velikhov believes that an important feature of the conference was that its participants declared that it was feasible physically and technically to build the first thermo-

nuclear reactor in the 1990s. So, the project is expected to be realized by the year 2000. That is not half bad. The only question is whether the forecast made in the 1980s will come true in the 1990s.

Professor F. Engelmann pointed out: 'Now that the international situation is so tense it is of paramount importance to promote mutual understanding and cooperation among nations. It is also hard to overrate for mankind the cooperation among scientists who can find ways of effecting the most reasonable solution of many problems now facing the world. Therefore, we can only welcome the efforts of physicists and engineers who participate in "Intor", the promising international project being carried out under the auspices of the International Atomic Energy Agency in Vienna. The Moscow conference has noted the successes scored by this joint work. It has shown not only the possibility of taking another, qualitatively new step towards the mastery of thermonuclear energy, but also the will of scientists from countries with different social systems to work successfully together.'

Many years ago at a reception given by Kapitza at the Institute of Physical Problems (he had just been awarded the title of Hero of Socialist Labour) E. L. Andronikashvili recalls that Pyotr Leonidovich asked Kurchatov a humorous question: 'Igor Vasilyevich, why do you wear such a long beard?'

Without waiting for an answer he went on:

'It evidently helps you to keep secrets better. The words accidentally escaping Igor Vasilyevich's lips get caught in his beard and do not reach the ears of the person he is talking to.'

But in fact it was Kurchatov who first made public the investigations on controlled fusion conducted in the USSR by talking about them in his report at the Atomic Energy Research Establishment in Harwell (England) in 1956 (at that time the Establishment was headed by Kapitza's friend John Cockcroft).

At present physicists are following the most fruitful path of international cooperation both in research into fusion and in other scientific fields, for example, space exploration. Design of thermonuclear reactors in the first approximation, as it were, is being jointly carried out.

Let us return to Kapitza's report at the international forum of nuclear scientists in Moscow. Pyotr Leonidovich briefly reminded those present of the history of investigations of high temperature plasma. Apart from installations with magnetic and inertial plasma confinement, Kapitza said, there also exists a third approach to the thermonuclear reactor based on continuous heating of the plasma. Up to now this method has been developed only at the Institute of Physical Problems of the USSR Academy of Sciences. As distinct from Tokamak and the laser implosion method for producing the necessary conditions for the thermonuclear process, the new method was not specially invented; while developing a high-power, continuously operating microwave generator we 'accidentally discovered a hot plasma phenomenon.'

To explain how it all happened Kapitza had to return to the times when he stayed almost constantly on Nikolina Hill. 'Beginning in 1950', said Pyotr Leonidovich, 'we developed a high-power, continuously operating microwave generator operating at 20-cm wavelength with a power of a few hundred kilowatts. The generator was called the Nigotron (see page 110). During the tests of one of our early models, a high-power microwave was passed through a quartz sphere filled with helium at a pressure of 10 cm-Hg. A bright discharge with well-defined boundaries was observed, but only for a few seconds because the quartz sphere melted through in one place. These observations led, first, to the suggestion that ball lightning has the same nature and may be due to high-frequency waves which are produced by a thunderstorm cloud after the conventional lightning discharge; and, second, they opened up a new possibility to produce high-temperature plasma.'

Pyotr Leonidovich found it necessary to note the intensification of research into high-temperature plasma. He said:

'During the last few years we, at the Institute of Physical Problems, have concentrated on the study of the physical properties of this type of plasma and we have become more and more convinced that these researches are opening up new possibilities for attaining thermonuclear fusion on a large scale, which has certain advantages as compared with the pulsed modes. Lately progress has been made in this

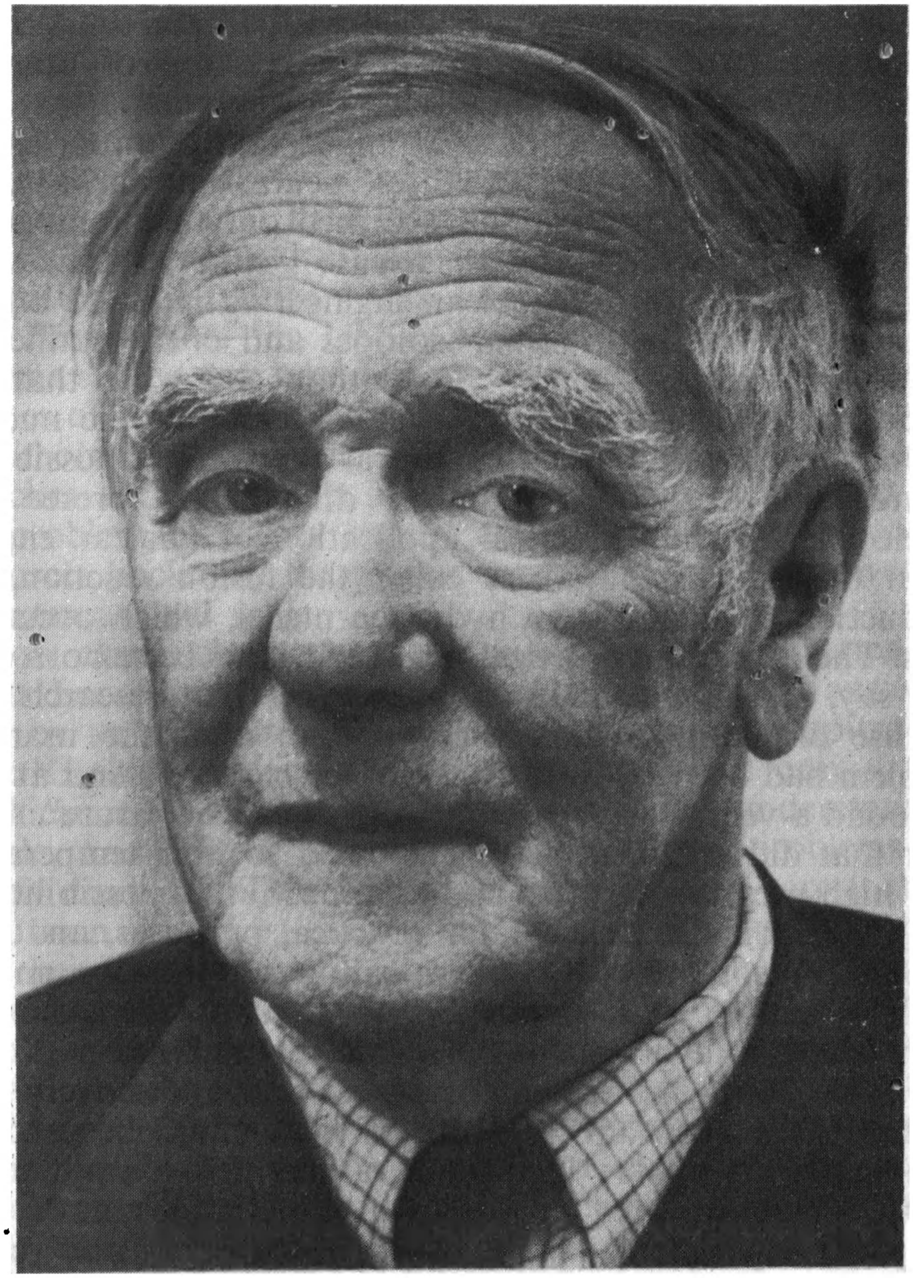
work at the Institute of Physical Problems with the participation of a considerable number of scientists working in the Physical Laboratory. Now this work is at the stage when we can, with greater certainty, evaluate the emerging possibilities. Last year (1980) sufficient progress was made in realizing clearly the difficulties in applying the properties of our plasma to controlled thermonuclear fusion. The main difficulties in producing high-temperature plasma by our method are the supply of high-power continuous microwave radiation to feed the plasma discharge, and the stabilization of this discharge freely floating in a gaseous medium.'

Kapitza dwelt at length on the installations built for the experiments and examined the investigations carried out on them. He warned that physicists would be confronted with new, even more complex problems in the process of plasma research.

'Another problem which has to be solved', Pyotr Leonidovich went on, 'is the heat loss at the end of the filament. This heat loss is due, first, to the fast particles in the plasma which may exist at the "tail" of the velocity distribution function and, second, the ordinary thermal particles. But these losses can be compensated by changing the linear plasma filament discharge for a circular plasma filament discharge. For this we must have a toroidal multi-slit resonator, which could be the foundation of a future thermonuclear reactor. The complexity of the problems encountered on the way to its implementation underlines the absolute necessity of carrying out all experiments with the greatest care and accuracy. Without a deep understanding of the processes taking place in the plasma we shall never be able to understand the mechanism of filament formation.'

In conclusion Kapitza said that the study of processes occurring in high-temperature plasma is at the stage when physical phenomena are ahead of theory. Kapitza's original approach to solving this problem – production of high-temperature plasma in the form of plasma filament fed by high-frequency current from special generators of the Nigotron type – is the contribution to the competition mentioned by Academician Ginzburg.

It is common knowledge that physicists concerned with problems of thermonuclear fusion, including theorists, have a great deal of work to do. During this work there may



Pyotr Leonidovich Kapitza, 1977

appear a brilliant idea which will force the researchers to deviate from old paths, like the idea which in the early 1930s led to the discovery of the chain reaction of uranium fission, and due to which practical use of nuclear energy became a reality. Before this discovery was made many scientists, including Rutherford, the creator of nuclear physics, doubted that a nuclear reaction could be controlled and practically applied.

In 1960, Academician Ya. B. Zeldovich (three times Hero of Socialist Labour) called the chain reaction of uranium fission 'a "freak of nature" in a sense, however important it is today. Nature could well have arranged that uranium fission would produce not two or three neutrons, but, say, an average of 0.7. Or it might have turned out that radioactive disintegration would only release either alpha- or beta-particles. So far all nuclear engineering is based on the fission of one of the uranium isotopes and of the artificially created plutonium element. So, without knowing that the phenomenon of disintegration (such as fission of the nucleus accompanied by the release of several neutrons) is possible in nature even Rutherford found it difficult to foresee this development in the practical application of nuclear energy.

On the other hand, there exists the fusion reaction, i.e. production of helium from hydrogen nuclei, which occurs in stars. The idea of its practical use could have been born long ago, say, as early as 1932-1933. The fact that research into the use of thermonuclear energy began after the uranium problem had been resolved is a kind of paradox. And at first we found a very special case due to "a freak of nature". Only after that did scientists get accustomed to high-temperature and high-pressure physics and approach the possibility of using thermonuclear energy for practical purposes, and only by burning isotopes of hydrogen – rare natural deuterium and artificial tritium. It is impossible to simulate the stars and burn ordinary hydrogen in terrestrial conditions.'

Not so long ago an important scientific discovery was made: that a quantum generator of light could be used for heating plasma to very high temperatures (tens of millions of degrees). Sophisticated experimental installations have been designed; experiments which have yielded promising results are well under way. But will the long-awaited goal be reached?

In the summer of 1982 Kapitza interrupted his work for a while and together with his wife made a trip to the island of Sicily, Italy. The town of Erice near Palermo had been chosen as the venue for the 2nd International Workshop of Scientists on Global Aspects of a Nuclear War. To participate in this important forum Kapitza made a tiring air trip from Moscow to Rome where he boarded another plane

which took him and his wife Anna Alexeevna on to Palermo, the capital of Sicily.

The Workshop was held on 20–23 August at the local Centre of Scientific Culture. When the hot Sicilian summer was at its height many prominent physicists from different countries arrived at Erice. Among the participants was Paul Dirac, Kapitza's old friend from Cambridge. The Soviet delegation at Erice was headed by E. P. Velikhov, Vice-President of the USSR Academy of Sciences.

Anna Alexeevna read Kapitza's paper which recalled themes of Kapitza's lecture 'Global Problems and Energy' at Stockholm University in 1976. In his paper, as in his other speeches and statements, Pyotr Leonidovich maintained that the problem of energy supply and the utilization of energy resources (including thermonuclear fusion) must be solved on an international scale.

How can nuclear and thermonuclear wars be averted? In Pyotr Leonidovich's opinion this question can be answered only by an international effort of scientists. As Kapitza has said: 'Global problems can be effectively solved only if their significance for the fate of humanity is widely understood by people, and this is possible provided these problems are widely discussed. Therefore scientists must take care that the discussion should be carried out on a strictly scientific basis and be independent of the narrowly selfish interests of individual countries. Of course, the solution of global problems must be based on the ethical obligations of man toward society regardless of national or political emotions.'

The arsenal of technology of the outgoing century does not as yet include a thermonuclear reactor. But it will be created despite all the difficulties to be encountered. This will be the apotheosis of the development of the magnificent ideas and experiments of scientists who strive not only to unravel the deep mysteries of nature but also to improve the life of mankind. Then we shall be able to assess once again the work done by Academician Pyotr Leonidovich Kapitza whose life and scientific discoveries are indivisible, the work which by its singularity and significance amazes any one living in our remarkable 20th century.

Main Biographical Dates

1894	Born in Kronstadt, near St. Petersburg, 9 July
1912	Finished technical school; entered St. Petersburg Polytechnical Institute
1918-21	Lecturer at the Petrograd Polytechnic, and researcher at the Physico-Technical Institute, Petrograd
1921-24	Researcher at the Cavendish Laboratory, Cambridge
1923	Awarded doctorate, Ph.D.
1923-6	Clerk Maxwell Student
1924-32	Assistant Director of Magnetic Research, Cavendish Laboratory
1925-36	Fellow of Trinity College, Cambridge
1929	Fellow of the Royal Society of London Corresponding Member of the USSR Academy of Sciences
1930-34	Director of the Royal Society Mond Laboratory, and Messel Research Professor of the Royal Society
1931	Member of the French Physical Society (from 1935 Foreign Member of its governing council)
1935-46, **1955-**	Director of the Institute of Physical Problems (USSR Academy of Sciences), Moscow
1939	Full Member of USSR Academy of Sciences
1943-46	Head of the Department of Oxygen Industry, directly responsible to the USSR Council of Ministers
1944-46	Professor and Head of the Department of Low-Temperature Physics, Moscow University
1947-50	Head of the Department of General Physics, Physico-Technical Faculty, Moscow University
1950-55	Senior Research Associate of the Institute of Crystallography (USSR Academy of Sciences), Moscow
1955	Became Chief Editor of the *Journal of Experimental and Theoretical Physics* (in Russian)
1956	Head of the Department of Low-Temperature Physics and Cryogenics in the Physico-Technical Institute, Moscow
1957	Elected member of the Presidium of USSR Academy of Sciences
1978	Nobel Prize in Physics

Works by P. L. Kapitza

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22. 'The scientific activity of Benjamin Franklin', *Usp. Fiz. Nauk* **58**, 169 (1956).
23. 'How is atomic war to be prevented?', *Novoe Vremya* **14**, 8 (1956).
24. 'Some aspects of the organization of scientific work', *Pravda*, 4 May, 1957; *World of Science* **1**, 14 (1959).
25. 'The future of science', *World of Science* **4,** No. 3-4, 2, (1960); *Nauka i Zhizn'* 3, 18 (1962).
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29. 'The physicist and public figure Paul Langevin', *Zhizn' dlya Nauki*, Znanie, Moscow, 1965, p. 54.
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32. 'Recollections of Lord Rutherford', *Proc. Roy. Soc.* **A**, **297**, 123 (1966).
33. 'Aleksandr Aleksandrovitch Fridman', from *Selected Works of A. A. Fridman*, Nauka, Moscow, 1966, p. 397.
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42. 'The centenary of the Journal of experimental and theoretical physics and the role of journals in the development of science', *Usp. Fiz. Nauk*, **111**, 535 (1973); *Soviet Phys.–Uspekhi* **16**, 928 (1974).
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44. 'Reading M. M. Prishvin's diary', *Sever*, No. 6, 69, 1975; from 'Prishvin and Present Times', *Sovremennik*, Moscow, 1978, p. 147.
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47. 'Global problems and energy', *Usp. Fiz. Nauk* **122**, 327 (1977); *Soviet Phys.–Uspekhi* **20**, 547 (1977).
48. 'The impact of modern scientific ideas on society', *Voprosy filosofii*, No. 1, 61 (1979).
49. 'Shakespeare and Bacon', *Izobretatel' i Ratsionalizator*, No. 2, p. 14 (1983).

Books

1. *Collected Papers of P. L. Kapitza*, edited by D. ter Haar; Pergamon Press, Oxford; Vol. 1, 1964; Vol. 2, 1965; Vol. 3, 1967; (Vol. 4 forthcoming).
2. *High-Power Microwave Electronics*, Nauka, Mocsow, 1962, 194 pp.; English edition; Pergamon Press, Oxford, 1964, 148 pp.
3. *Life Devoted to Science (Lomonosov, Franklin, Rutherford, Langevin)* Znanie, Moscow, 1965, 62 pp.
4. *Theory, Experiment, Practice,* Znanie, Moscow, 1966, 47 pp.
5. *Physics Problems*, Znanie, Moscow, 1972, 46 pp.
6. *Experiment, Theory, Practice*, Nauka, Moscow, 1974, 288 pp.; 2nd edition, 1977, 350 pp.; English translation (edited by R. S. Cohen) with additions; Dordrecht, Boston and London, D. Reidel Publ. Co., 1980.
7. *Science, Mankind, Organization*; in Japanese; Misuzu Shobo, Tokyo, 1974, 273 pp.
8. *Le Livre du Problème de Physique*, Edition CEDIC, Paris, 1977, 70 pp.

Abbreviations

J. Phys. USSR/ Zh. Eksp. Teor. Fiz.	The *Journal of Experimental and Theoretical Physics* (in Russian) (from 1907 to 1930 published as the *Journal of the Russian Physical and Chemical Society, Physics Section* or J. Russ. Phys. Chem. Soc., Phys. Sect.)
Bull. Roentgenol. Radiol.	The *Bulletin of Roentgenology and Radiology* (in Russian)
Proc. Roy. Soc.	*Proceedings of the Royal Society*
Usp. Fiz. Nauk	*Advances in the Physical Sciences* (in Russian)
Physik. Zs.	*Physikalishe Zeitschrift*
Zs. f. Physik	*Zeitschrift für Physik*
J. Sci. Instrum.	*Journal of Scientific Instruments* (in Russian)
Doklad. Akad. Nauk	*Doklady Akademii Nauk* (Papers of the USSR Academy of Sciences)
Zh. Teor. Phys.	The *Journal of Theoretical Physics* (in Russian)

P. L. Kapitza's Honorary Memberships

Fellow of the Royal Society, London 1929.
Member of:
the USSR Academy of Sciences, 1939 (Corresponding Member – 1929);

the French Physical Society, 1931;
the Institute of Physics, England 1934;
the International Academy of Aeronautics, 1964.

Honorary Member of:
the Moscow Society of Naturalists, 1934;
the Institute of Metals, England 1943;
the Franklin Institute, USA 1946;
the New York Academy of Sciences, 1946;
the Indian Academy of Sciences, 1947;
the Royal Irish Academy, 1948;
the National Institute of Sciences of India, 1957;
the German Academy of Naturalists 'Leopoldina', GDR 1958;
the International Academy of the History of Science, 1971;
the Tata Institute of Fundamental Research, Bombay, India 1977.

Foreign Member of:
the Royal Danish Academy of Sciences and Letters, 1946;
the National Academy of Sciences, USA 1946;
the Indian National Sciences Academy, 1956;
the Polish Academy of Sciences, 1962;
the Royal Swedish Academy of Sciences, 1966;
the American Academy of Arts and Sciences, 1968;
the Royal Netherlands Academy of Sciences, 1969;
the Serbian Academy of Sciences and Arts, 1971;
the Finnish Academy of Arts and Sciences, 1974.

Honorary Fellow of:
Trinity College Cambridge, 1966;
Churchill College Cambridge, 1974.

P. L. Kapitza's Honorary Doctorates

D. Sc. (Physics and Mathematics), USSR Academy of Sciences, 1928;
D. Sc., Algiers University, 1944;
Sorbonne, Paris, 1945;
D. Ph., Oslo University, 1946;
D. Sc., Jagellonian University, 1964;
Technische Universität Dresden, 1964;
Charles University, Prague, 1965;
Columbia University, New York, 1969;
Wroclaw Technical University, 1972;
Delhi University, 1972;
Université de Lausanne, 1973;
D. Ph., Turku University, 1977.

P. L. Kapitza's Awards

1941, 1943 – USSR State Prize
1943, 1944, 1945, 1964, 1971, 1974 – Order of Lenin
1945, 1974 – Title of Hero of Socialist Labour, and 'Hammer and Sickle' Gold Medal
1946 – Medal 'For Valiant Labour in the Great Patriotic War of 1941-1945'
1954 – Order of the Red Banner of Labour
1959 – Lomonosov Gold Medal of the USSR Academy of Sciences
1962 – Great Gold Medal of the USSR Exhibition of Economic Achievements

1923 – James Clerk Maxwell Prize, Cambridge University, England
1934 – Medal of the Liége University, Belgium
1942 – Faraday Medal of the Institute of Electrical Engineers, England
1944 – Franklin Medal of the Franklin Institute, USA
1955 – Sir Devaprasad Sarbadhikary Gold Medal of the Calcutta University, India
1959 – Kothenius Gold Medal of the German Academy of Naturalists 'Leopoldina', the GDR
Frèdèric Joliot-Curie Silver Medal of the World Peace Council
1964 – Medal for Merits in Science and to Mankind of the Czechoslovak Academy of Sciences
1965 – International Niels Bohr Medal of the Danish Engineering Society
1966 – Rutherford Medal of the Institute of Physics and Physical Society, England
1967 – Order of the Yugoslav Banner with Ribbon
1968 – Golden Kamerlingh Onnes Medal of the Netherlands Society of Refrigeration
1969 – Rutherford Memorial Lecture, Royal Society of London
1973 – Simon Memorial Award of the Institute of Physics and Physical Society, England
1974 – Copernicus Memorial Medal of the Polish Academy of Sciences
1977 – Bernal Memorial Lecture, Royal Society of London
1978 – Nobel Prize in Physics
1981 – Helmholtz Medal of the Academy of Sciences of the GDR
– Medal for Outstanding Contributions to Physics Education of the International Commission on Physics Education
1982 – Gold Medal for Merits in Science and to Mankind of the Czechoslovak Academy of Sciences

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